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INDIVIDUAL DIFFERENCES IN MENTAL IMAGERY PROCESSES.(U)

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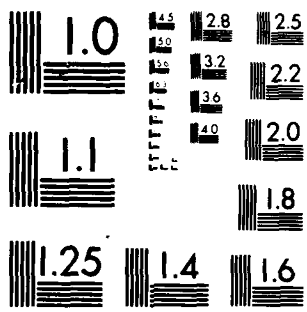

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Individual Differences in Mental Imagery Processes

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Stephen Kosslyn (1980) developed a theory of mental imagery that specifies the nature of the information structure and the processes that operate on the structure. Six tasks were developed to measure processes postulated in the theory. Seventy-nine adult subjects completed these basic process tasks, eight spatial ability tests, three self-report tests, and both free-recall and cued-recall memory tests.

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Analyses focussed on the relationships with performance on the basic process tasks. Performance on spatial ability tests was consistently related to mental rotation and image integration abilities, suggesting that these processes are involved in spatial reasoning. Efficiency of image generation was related to spatial ability performance when a spatial representation was presented verbally rather than pictorially. Memory performance and self reports of imagery control and vividness were weakly related to basic imagery processes.

INTRODUCTION

The development of effective imagery strategies for educational settings is analogous to an engineering problem. Engineering solutions are derived by creatively applying scientific principles induced from research. However, the principles which have guided educational research on imagery are those specified by the ancient Greeks. Indeed, much of the recent psychological research on imagery has investigated the validity of those ancient principles. However, recent research has moved in several directions that hold promise for development of new principles. These researchers are addressing three questions: (1) how imagery functions, (2) what situations are appropriate for the use of imagery, and (3) who will benefit most from imagery strategies. Each of these directions is elaborated below.

How Imagery Functions

Theoretical advances in scientific understanding of the processes that comprise mental imagery are largely due to the work of Stephen Kosslyn and his colleagues (e.g., Kosslyn, 1975; Kosslyn & Pomerantz, 1977; Kosslyn, 1980). Kosslyn has systematically studied the functional properties of visual imagery and developed a model of visual imagery processes (Kosslyn, Pinker, Smith, & Schwartz, 1979). This model of imagery has been instantiated in a computer simulation in which images are represented on a two-dimensional surface such as a cathode ray tube (CRT). This CRT has fine resolution in the center, and becomes increasingly coarse as the boundaries are approached. Images are generated on the CRT and manipulated by means of some basic processes. These processes can rotate, scan, shrink, or expand an image or part of an image. Other processes find particular parts of an image and add detail.

Kosslyn has pursued an active program of research to test and expand his theory and model. The CRT model was motivated by findings that more time is required to answer detailed questions about small images than big images (Kosslyn, 1975). In addition, subjectively larger images take longer to generate than small images (Kosslyn, 1975). Differential resolution on the CRT was motivated by findings that enlarging an image causes it to become too big to be seen, and the point at which the image becomes too big depends on the subject's criterion (Kosslyn, 1978). The role of pattern recognition processes operating on images was confirmed by the finding that the time required to verify that an animal has a certain body part increases as the size of the part decreases. Furthermore, this finding holds only if subjects use an imagery strategy. When subjects were not instructed to use an imagery strategy the size of the body part did not influence response time, but the strength of the association between the animal and body part did influence response time (Kosslyn, 1976).

Situations Appropriate for Imagery Strategies

Despite the effectiveness of imagery as a learning aid, it is rarely recommended or taught in educational or training

environments. Perhaps imagery is not recommended because it is not considered an effective strategy for the material to be learned. This section addresses the problems associated with applying imagery to a variety of learning tasks. First, those situations are considered for which imagery is well-suited. Then mnemonic devices which extend the usefulness of imagery are examined. Finally, the obstacles to development of new mnemonic devices are considered.

One of Paivio's major contributions to psychology was to establish that memory performance for a word is largely determined by how easily the word's referent can be imaged (Paivio, 1971). Concrete words are more easily represented in an image than are abstract words, and concrete words are remembered better than abstract words. Furthermore, abstract words which readily elicit an image (e.g., religion) are more memorable than words which are difficult to image (e.g., quality). Pictures are remembered even better than concrete words, presumably because pictures are the best possible stimulus for generating a visual image. These findings have been extended to show that more complex stimuli such as word triads (Paivio & Begg, 1971), sentences (Davies & Proctor, 1976), and connected discourse (Yuille & Paivio, 1969) are more memorable if the ideas represented are more concrete. Thus imagery is an effective learning strategy when the material to be learned involves concrete objects, and if the relationships between objects are concrete. It would probably not be effective in a philosophy course dealing with abstract issues. However, it could be very helpful in engineering, physical sciences, or technical courses which teach relationships among concrete objects. Even the abstract ideas in a physics course can often be translated into concrete examples.

Much of the psychological research has examined the effectiveness of imagery in paired-associate learning (Paivio, 1971). This research has confirmed the importance of concreteness in this task also. Interestingly, the concreteness of the stimulus term is much more important than the concreteness of the response. Apparently, presentation of the stimulus term during a test elicits retrieval of an image when the stimulus is concrete. When an image is retrieved, the response term can be obtained by examination of the image.

Some of the limitations of imagery have been overcome by the development of mnemonic devices. These methods take advantage of the effectiveness of imagery for associating concrete stimuli. The mnemonic devices combine imagery with a memory structure to facilitate learning relationships which are not readily imaged. For example, suppose an ordered list of words is to be remembered. One could attempt to image the objects represented by the words standing in a line. However, this is not an interactive image and may not be readily learned. Alternatively, one could generate an image associating the first and second words, then another image to associate the second and third words, and so on. In fact this strategy is effective, but not as effective as the pegword system or the method of loci. These two methods are similar, so only the method of loci is considered here.

Before using the method of loci, a mnemonist must learn a sequence of locations that, preferably, are near one another and are easily imagined. For example, the rooms in one's home would be appropriate. As each word is presented, the mnemonist simply imagines the second object in a room, then advances to the next room. The words can be recalled in order by simply imagining a walk from room to room, recalling the objects from the image of the room.

This mnemonic technique deserves more careful attention to discover how it works. Imagery is used to associate two or more items; in this case, the rooms and objects. The mnemonic device provides a structure that is well known and is analogous to the structure to be learned. In this instance, the mnemonist wants to learn an ordered list of words, so a linear ordering of rooms is connected to the words in the corresponding order.

Who Benefits From Imagery Strategies?

What aspects of imagery ability influence the effectiveness of an imagery learning strategy? This section briefly reviews current literature relevant to this question. Thoughtful and extensive reviews of this area have recently been prepared by White, Sheehan, and Ashton (1977) and by Ernest (1977).

Questionnaires remain the most frequently used method of assessing individual differences in imagery ability. Questionnaires have been designed to assess imagery vividness, imagery control, or preference to use visual versus verbal strategies. Numerous studies have verified the validity and reliability of these tests (White et al., 1977). However, psychometric studies have questioned whether tests of vividness and tests of control really measure different processes. The correlations of these tests with learning measures presented below suggest that vividness and control really are distinct (Ernest, 1977).

The study of individual differences in imagery ability has a long history, but not a particularly glorious one. Despite the volume of research, few interesting relationships have been observed. Researchers remain strongly interested in imagery vividness despite consistent failures to find significant correlations with vividness. Indeed, why should vividness be related to any cognitive processes involving imagery? To assume such a relationship exists is to assume a certain class of theories, and these theories consistently have been refuted. Marks (1973) found that people who report little or no imagery can effectively use imagery mnemonic strategies. Thus, imagery vividness is not an important part of the function of imagery. This aspect of imagery may represent an epiphenomenon.

A theory of imagery is the natural source for hypotheses regarding individual differences in imagery ability. In particular, Kosslyn's theory provides the level of description required to generate hypotheses. His theory emphasizes the role of image generation, scanning, rotation, shrinking, and enlarging. Furthermore, Kosslyn distinguishes between transformations of an

entire image and part of an image. These processes are reasonable candidates for the source of important individual differences. Indeed, the relationships found with imagery control and spatial ability are a partial confirmation of these hypotheses. Obviously, both imagery control and spatial ability depend on the ability to generate and manipulate parts or all of an image.

OVERVIEW OF RESEARCH

All of the basic issues discussed above were investigated. First, Kosslyn's model of "how imagery functions" provides the theoretical basis for the research. According to this model, imagery is composed of several basic cognitive processes which construct and transform images. Three of these basic functions, Picture, Put, and Find, are explored in this research. Briefly, Picture is a function to generate an image, Find will search for a certain part of an image, and Put will elaborate or reorganize an image. The Find function may be decomposed further into functions that Zoom in on an image, Pan back from it, Scan it, or Rotate it. If Kosslyn's model is correct, then all imagery tasks involve some combination of these basic processes. Thus, tasks were developed to measure efficiency or ability to perform these basic imagery functions.

The "situations that are appropriate for mental imagery" must depend on the ability of an individual subject to apply these functions in a specific situation. A task requiring mental rotation is perfectly suited for the use of imagery if the subject is capable of mental rotation. If the rotation process is not available to the subject, another strategy may be developed or performance may suffer. A range of complex tasks were selected that appear to require combinations of the basic processes proposed by Kosslyn. If subjects use these basic processes to perform the tasks, then performance on these tasks should be predictable from performance on the corresponding basic process tasks.

To determine "who benefits from mental imagery," self-report questionnaires and memory tests were administered. The conclusions of prior research are that memory performance is not related to imagery vividness but is related to imagery control and spatial ability. Presumably, imagery control and spatial ability reflect the efficient operation of basic cognitive processes. Thus, the relationship between the efficiency of basic processes and subjects' reports of vividness and control were examined. Similarly, the relationship between memory performance and both self-report and basic process measures were examined.

General Method

Procedure

The ordering of tasks and the order of trials within tasks was the same for all subjects. The experiment consisted of two sessions on two different days. In the first session subjects were tested individually. This session required from 1.5 to 3.5

hours, depending on the subjects' speed in self-paced tasks. All of the basic function tasks and a few of the spatial tasks took place in the individual session. In the second session subjects were tested in groups. Group sessions lasted about two hours. All of the memory tasks, self-report questionnaires, and most of the spatial tasks took place at the group session. (See Table 1 for the task order.) Subjects were paid at the end of the group session.

Equipment

In many of the tasks in the first session a computer-controlled slide projector was used to present stimuli. Stimuli were controlled and responses were collected by a Charles River Data Systems MF-211 computer with an LSI 11/03 central processor. ADAC Model 1300/HCO and 1616/CCI digital input and output panels provided the interface between the computer and other equipment. The computer determined when a Kodak Ektagraphic slide projector advanced to the next slide through use of the projector's remote controls. The computer also controlled when each slide was presented through use of a Gerbrands Model 66 electronic shutter attached to the lens of the projector.

Slides were projected on a screen approximately 7 feet from the projector. Subjects sat just to the left and in front of the projector facing the screen. Subjects held two response buttons, one in each hand, while the experimenter held a third response button. The computer was programmed to recognize the experimenter's button as a signal to start either the experiment or the main trials after a set of practice trials. The subjects' response buttons were used to respond to each stimulus. After each response, the computer advanced to the next slide, and after a programmed interval of 1 second the shutter was opened to present the slide. The interval between stimulus onset and the response was measured to the nearest hundredth of a second by means of a programmable clock.

In some tasks stimuli were presented auditorily. The stimuli were recorded in advance and presented by means of a Sony Model TC-252 tape recorder. Stimuli were presented through a speaker at a comfortable listening level.

Subjects

Seventy-nine subjects were recruited from the University of Denver community through campus newspaper advertisements, posters, and classroom announcements. Each subject was paid $15.00 for participation in the experiment. There were 39 males and 40 females. All 79 subjects participated in the individual session, but only 77 subjects (39 males and 38 females) participated in the group session.

BASIC IMAGERY PROCESSES

Any theory of imagery must postulate a data structure and a set of processes or functions that operate on the structure.

Individual differences in imagery vividness or imagery control could be due to differences in the quality of the data structure or the efficiency of some or all of the processes. Ideally, separate measures of structure quality and process efficiency should be obtained for each structure and process. In practice, however, structure and process are inextricably intertwined in any measures of performance. Slow performance in a task could be due to inefficiency of the processes required for that task or a data structure that is inadequate for the task. Similarly, inaccuracy in a task could be due to inadequate data structures or processes that are so inefficient that the task cannot be performed. Because individual differences in process and structure are inseparable, it is convenient to assume that structure quality is one component of process efficiency. Thus, in the discussion that follows, individual differences are assumed to be entirely due to differences in efficiency.

Kosslyn's theory (Kosslyn et al., 1979; Kosslyn, 1980) postulates a set of basic functions that generate, transform, and inspect images. Image generation is accomplished by first generating a skeletal image structure, then adding detail as required. In Kosslyn's simulation the Picture function generates each part of the structure, the Find function locates the position of detail, and the Put function integrates the detail with the existing image. The time to generate an image could depend on the efficiency of these functions or the amount of detail that a particular subject requires. The amount of detail included could determine the subjective vividness of an image.

Several tasks were developed in an attempt to separate the processes required to generate an image structure from those required to add, subtract, or integrate detail. In the first task subjects were simply asked to press a key when an image was formed. In two other tasks details were added to or subtracted from an image. In a fourth task several parts were integrated to form a complete image. The first of these tasks should emphasize the role of the Picture function, whereas the other three tasks emphasize the Find and Put functions.

Four basic image transformation functions were postulated by Kosslyn. These functions expand, shrink, rotate, or scan across all or part of an image. The transformation functions permit an image to be manipulated in much the same way as an actual visual scene. Indeed, the importance of imagery as a cognitive tool arises from the use of transformation functions. Inspection of an image is governed by the Find function described above, but often requires use of transformation functions to adjust that part of the image that is in central focus. The efficiency of both the scan and rotate functions were studied. One might expect the efficiency of these functions to determine the amount of control over images that a subject experiences.

<u>Picture Task</u>

The Picture function operates in conjunction with the Find and Put functions to generate the image required for further

operations. The efficiency of this collection of functions was assessed by asking subjects to form an image of a verbally-described object or objects. The subject was required to press a button when the image was formed, and the time was measured from stimulus onset to the subject's response. In a similar experiment Kosslyn (1980) found that the time to form an image increased by about 125 msec per object as the number of objects to be imaged increased from two to four. Furthermore, he found that the time to scan between two objects in the image increased with the distance between the objects. These results provide confirmation that people can use verbal descriptions to generate images.

In our task, subjects were simply asked to form visual images of verbally described scenes, and the time to form each image was measured. Paivio, Yuille, and Madigan (1968) demonstrated that more time is required to generate images from abstract words than concrete words. We conjectured that the time to generate an image might similarly depend on whether objects are ideal or real. To test this hypothesis, some of the descriptions involved real objects while others involved ideal objects, such as spheres and cubes. Furthermore, the number of objects in each scene was manipulated, but over a smaller range than that used by Kosslyn (1980); some scenes consisted of only one object while others consisted of two objects.

Method

Materials. Twenty phrases, verbal descriptions of scenes, were constructed. Ten of these phrases described real objects and ten described ideal objects. For both the real and ideal phrases, half the phrases described only one object and half described two objects. Examples of real/one-object, ideal/one-object, real/two-objects, and ideal/two-objects phrases are, respectively, "a ballet dancer," "a solid sphere," "a spoon in a cup," and "a pyramid on top of a cube." In addition, four practice phrases were constructed, one of each of the four phrase types. All phrases were photographed and presented separately on slides as white words on a black background. The order of presentation of the 20 descriptions was randomized, but remained constant for all subjects.

Procedure. Subjects were instructed to form "a mental picture or visual image" of the scene described on each slide. They were told that as soon as they could clearly "see" the scene described, to press the right-hand button. When a subject pressed the button to indicate that a visual image had been formed, the slide projector automatically advanced, and the next slide was presented. Subjects completed four practice slides, and had an opportunity to ask questions before viewing the 20 experimental slides.

Results

The mean times to create an image are presented in Table 2 as a function of the Real/Ideal dimension and the number of

objects to be imagined. As expected the time to create an image depended on the number of objects to be imaged, $F(1, 78) = 8.98$, $p < .005$. Generation of an image of two objects required 389 msec more than an image of one object, suggesting that this interval represents the time to generate each object. This interval of 389 msec is somewhat longer than the value of about 125 msec per object obtained by Kosslyn (1980), but much less than the value of 2520 msec obtained by McGlynn, Hofius, and Watulak (1974). Unfortunately, the 389-msec interval cannot be unambiguously interpreted. The verbal descriptions of two-object images were somewhat longer, requiring more reading time. The difference between the two conditions could be largely due to the difference in reading times.

Whether the objects to be imaged were real or ideal did not significantly affect the time to form an image, $F(1, 78) = 3.89$, $p > .05$. The mean effect was small, 235 msec, and not obtained consistently over subjects. The interaction of these two factors was nonsignificant, $F < 1$.

The mean time to create an image proved to be highly reliable, coefficient alpha = 0.852. This mean time will be used as a measure of the efficiency of the basic image picturing process.

Rotate Task

The Rotate function is a basic transformation process that is often required in complex spatial or imagery tasks. The Rotate process was assessed in a paradigm developed by Shepard and Metzler (1971). Pairs of two-dimensional representations of three-dimensional objects were presented to subjects. For half the pairs the two representations were of the same object, but the objects differed in orientation. In the remaining pairs the objects and orientations were both different. Subjects were required to determine whether the objects were the same or different. Shepard and Metzler were the first to establish that the time to complete this task increases linearly with the angular difference in orientation. The slope of the linear function provides a measure of the efficiency of the rotation process. Abilitities to maintain an image, rotate it, and compare images are measured by accuracy.

Method

Materials. The materials were selected from the stimuli used by Shepard and Metzler (1971), and kindly provided by Roger Shepard. Each stimulus consisted of two line drawings of three-dimensional, geometric objects. Fifty stimulus pictures and eight practice pictures were selected from the complete set. These stimuli were photographed and presented as white line drawings on a black background.

Half the 50 stimulus pictures depicted two identical objects (same set) and the other half depicted two objects which were mirror images of one another (different set). There were five distinct objects and there were five instances of each of these

distinct objects within both the same and different sets. Each instance depicted an object paired with itself (or its mirror image) rotated in depth. The angular differences in spatial orientation between pair members were 20, 60, 100, 140, and 180 degrees. Which member of the pair appeared on the left side of the picture and which on the right was randomly determined. The two members of a pair were positioned such that the center-to-center spacing subtended a visual angle of approximately 9 degrees; the height of each object subtended a visual angle of approximately 5 degrees.

Half of the eight practice pictures depicted objects which were the same, and half depicted objects which were mirror images of one another. The angular differences were 40, 80, 120, and 160 degrees for the practice pictures. The orders of presentation of the practice and stimulus pictures were randomized, but remained constant for all subjects.

Procedure. Subjects were instructed that pairs of three-dimensional objects would be presented, and the task was to determine whether the objects were the same or different, given that they were in different spatial orientations. Subjects were told that different objects would be mirror images of one another. Lastly, subjects were told to press the right-hand button if the objects were the same and the left-hand button if the objects were different.

During the eight practice trials subjects said each response aloud in addition to pressing the appropriate button. If a subject responded incorrectly to a practice trial, the experimenter repeated and elaborated the instructions before continuing with the next stimulus.

Results

This task proved to be difficult for our subjects. Table 3 presents proportion correct as a function of rotation angle and whether the objects were the same or different. A repeated measures Analysis of Variance revealed significant main effects of both angle of rotation and same versus different objects, $F(4, 312) = 11.22$ and $F(1, 78) = 18.17$, respectively, $p < .001$. The Angle X Same/Different interaction was also significant, $F(4, 312) = 4.15$, $p < .01$.

The mean RTs for correct responses are presented in Figure 1 as a function of rotation angle and same or different objects. Three subjects failed to answer any problems correctly in one condition. For these three subjects, means were estimated by multiplying the subject's mean RT times the ratio of the mean RT for that condition and the overall mean RT. An Analysis of Variance of the mean RTs revealed significant effects of angle, $F(4, 312) = 15.73$, $p < .001$, and of whether the figures were the same or different, $F(1, 78) = 77.23$, $p < .001$. The interaction of these factors also was significant, $F(4, 312) = 24.97$, $p < .001$ due to the fast RT for the different condition at 180 degree rotation. These results replicate the general pattern found by

Shepard and Metzler (1971) and others. The mean RTs for rotations of 180 degrees are less than would be predicted by the model that requires rotation followed by a comparison, but the 180 degree condition may well be a special case.

Both mean RT and proportion correct proved to be reliable measures, coefficient alpha = .974 and .839, respectively. However, the slope and intercept of the RT function provide more valid measures of Rotate function efficiency. Thus, the regression slope and intercept of the function relating the rotation angle to RT for correct responses on same trials were computed for every subject. Reliabilities of these statistics are not readily computed, but slope, intercept, and the correlation are determined from the mean RTs for each angle, and the reliabilities of these means can be computed. These mean RTs proved to be highly reliable; the mean alpha coefficient averaged over angles was .830.

When the results of individual subjects were examined, it became clear that some of the subjects were performing at accuracy levels near chance. These same subjects showed little relationship between RT and angle. Therefore, the slope and intercept for subjects who responded incorrectly on more than 20 percent of all trials were discarded, and only accuracy was retained as a measure of their rotation ability. Twenty-seven subjects were eliminated by this criterion.

Mean RTs for the same trials are presented in Figure 1 for the remaining 52 subjects. These results are in striking agreement with the model; RT increases linearly with angle. Furthermore, the linear model provided a good fit to the individual 52 subjects as evidenced by a mean correlation between RT and angle of .734. The mean slope and intercept were 28.67 msec/degree and 4217 msec, respectively. Again, these values are in close agreement with those obtained by Shepard and Metzler.

Add Task

Kosslyn et al. (1979) postulated that details are added to or subtracted from an image by the combined operations of the Find and Put functions. The purpose of the Add task was to assess ability to add detail to visual images. Subsequent tasks assessed other aspects of the Find and Put functions.

In the Add task subjects were asked to mentally add dots at specified locations in a base form. First the base form was presented, followed by five pictures of the base form and a dot in some location. Subjects controlled the rate of dot presentation by pressing a button when ready for the next dot. Thus, the time required for each dot by each subject provided a measure of the efficiency of the Add process. After the last dot was added subjects were required to identify the resulting image among a set of alternatives so that accuracy could be measured. There were two levels of difficulty to the task; the simpler level required adding dots to a triangle and the more difficult level required adding dots to a six-pointed star.

Method

Materials. Twenty-eight problems were constructed. Each problem required adding five dots, one at a time, to a base form. The base form was a triangle for the first 14 problems and a six-pointed star for the last 14 problems. The first two problems from each set of 14 were practice problems and the remaining 12 were test problems. The positions at which dots were to be added were chosen randomly from 13 positions on the triangle and 25 positions on the star, as shown in Figures 2(b) and 3(b). All pictures were photographed and presented separately on slides as white figures on a black background.

The first picture of each problem presented the base form without any dots. The next five pictures each showed the base form with one dot in some position on the form. The height of the triangles in these pictures subtended a visual angle of approximately 5.5 degrees; the height of the stars subtended a visual angle of approximately 6 degrees. The seventh picture showed six figures labelled 1 to 6. Each figure presented the base form and five dots. (Figures 2(a) and 3(a) illustrate sample problems.) One of the six figures represented the correct image; that is, the five dots were in the positions indicated on the five previous pictures. In the other five figures four dots were in the correct positions and a fifth dot was in a wrong position; the correct position for this fifth dot differed for each of the five distractor figures. The target (correct) figure appeared with the labels 1, 2, 3, 4, 5, and 6 in this last picture an equal number of times.

Procedure. The procedure is best described in terms of the instructions given to subjects. The instructions were as follows:

> In this next task, the first slide you'll see for each problem will show a blank triangle [first practice slide shown] exactly like this. After you see this first slide, you'll be presented with five slides; each of these slides will show the triangle with a dot in some position on the triangle [second practice slide shown] like this slide here. As you see each of these slides, imagine adding the dot to your image of the triangle in the position indicated. So, in the end you should have a mental picture of a triangle with five dots on it. The last slide for each problem will show six figures, each figure being a triangle with five dots on it. Your task is to detemine which of the six figures has the five dots in the positions indicated on the previous slides. When you decide on one of the figures, simply tell me your answer and simultaneously press the button in your right hand."

Subjects were also told that they would control the advancement of slides within each problem, and to simply press the button in their right hand when they were ready to see the next slide. They were told that, however, the experimenter controlled the advance from one problem to the next, i.e., that the

experimenter would control the advance to the first slide of each problem. The experimenter recorded the subject's answer to each problem, gave feedback to the subject on the accuracy of the answer, and then advanced to the first slide of the next problem.

After completing the Triangle problems, subjects were instructed that the remaining problems would be similar, but the base form would be a star. Again, two practice problems and 12 experimental problems were presented.

Results

The mean number of correct responses was 9.01 for triangles and 9.46 for stars. According to a repeated measures Analysis of Variance there was no significant difference in accuracy for the two base forms, $F(1, 78) = 3.31$, $p > .05$. Of course, neither the presence nor the absence of an effect is interpretable because the base forms were confounded with practice. The stars were always presented after the triangles.

Mean RTs are presented in Table 4 as a function of the base form (triangle or star) and the ordinal position of the dot to be added. Subjects were considerably slower when adding dots to a star despite the effects of practice, $F(1, 78) = 39.92$, $p < .001$. Furthermore, subjects slowed with the addition of each new dot, producing a highly significant Position main effect, $F(4, 412) = 60.86$, $p < .001$. The increase in time with each succeeding dot was considerably greater for stars than for triangles, resulting in a significant interaction, $F(4, 412) = 10.47$, $p < .001$. For both the triangles and stars mean RT increased approximately linearly with dot ordinal position, resulting in a correlation between mean RT and dot ordinal position of .991.

Correlations of mean RT and ordinal dot position were computed for all subjects. The mean and standard deviation of the correlations were .744 and .429, respectively, indicating that the linear relationship observed for mean RTs applied to individual subjects also. To measure the efficiency of the add process, linear regression slopes and intercepts were computed for each subject. The reliabilities of these slopes and intercepts are not easily determined, however the reliabilities of the mean RTs used to calculate these slopes and intercepts can be readily determined. The mean alpha coefficient averaged over the five dot positions was .927, indicating these mean RTs were highly reliable. The mean and standard deviation of the slopes were 565.5 and 544.0 msec/dot, respectively. The mean and standard deviation of the intercepts were 1.690 and .122 sec, respectively.

Subtract Task

The Subtract process is complimentary to the Add process. Although Kosslyn et al. (1979) and Kosslyn (1980) did not address how detail might be purposefully removed from an image, it is clear from the theory that the Find and Put functions are required. The purpose of the Subtract task was to assess ability

to mentally delete parts of an image. The procedure for each problem was similar to that followed in the Add task. A base form was presented with dots at every possible position, followed by a sequence of self-paced pictures indicating which dot should be subtracted from the image. At the end of the sequence subjects were required to identify the resulting image among a set of alternatives. Task difficulty was manipulated by including both triangles and stars as base forms. Both accuracy and the time to view each slide were measured.

Method

Materials. Twenty-eight problems were constructed. Each problem involved deleting five dots from a base form containing 13 dots. The base form was a triangle in the first 14 problems and a six-pointed star in the last 14 problems. The first two problems of each set were practice problems and the remaining 12 were test problems.

The first picture of each problem was of the base form with all its 13 dots. The next five pictures each showed the base form with a dot in one of the 13 positions. The height of the triangles in these pictures subtended a visual angle of approximately 5.5 degrees; the height of the stars subtended a visual angle of approximately 6 degrees. The last picture showed six figures labelled 1 to 6. (Figures 4 and 5 depict sample problems.) Each figure was the original form with dots in 8 of the 13 positions. Only one of these figures was the correct image; that is, it had no dots in any of the positions indicated in the five previous pictures. The other five figures had a dot in one of the positions indicated in the five previous pictures; this position was different for each of the five distractor figures. For both sets of 12 test problems, the target (correct) figure appeared with the labels 1, 2, 3, 4, 5, and 6 in this last picture an equal number of times.

Procedure. The procedure for the Subtract task was similar to that for the Add task. Before beginning the Triangle problems, subjects were instructed as follows:

> The next set of problems is a lot like the one where you added dots to a triangle. Here, instead of adding dots to a triangle, you'll be subtracting dots from this figure [first practice slide shown]. So, the first slide for each problem will look just like this one here. This triangle has 13 dots on it: a pair of dots at each corner, one on the inside and one on the outside, a pair of dots at the middle of each side, one on the inside and one on the outside, and a single dot in the very middle. After you see this first slide, you'll see five slides, each showing the triangle and one dot in some position on the triangle. Imagine subtracting these dots from your image of this original figure. In other words, you'll be subtracting five dots from this figure and will end up with a triangle having eight dots. The last slide you'll see for each problem will show six figures, each figure being a triangle with eight dots on it.

> Your task is to decide which of these figures shows the eight dots in the positions left over after you've taken away the five dots shown on the previous slides. Again, tell me your answer at the same time as you press the button in your right hand.

As with the Add task, the subject controlled the advance of slides within problems, and the experimenter recorded subjects' answers and gave feedback on the accuracy of each answer. After all triangle problems were completed, subjects were instructed that the base form would be a star in the remaining problems. Again, two practice problems and 12 test problems were completed.

Results

Because of computer failure during the Subtract/Stars Task, the data for two subjects on this task were discarded. Therefore, data for only 77 of the 79 subjects were included in subsequent statistical analyses involving the Subtract/Stars Task.

The mean number correct was 9.34 for triangles and 9.38 for stars. There was no signigicant difference in number correct between the two conditions, $F < 1$.

Mean RTs are presented in Table 4 as a function of base form (triangle or star) and ordinal position of the dot to be subtracted. Surprisingly, the effect of the base form was negligible, $F < 1$. Mean RT increased nearly .5 sec for each additional dot resulting in a significant Position main effect, $F(4, 304) = 80.20$, $p < .001$. A significant Form x Position interaction, $F(4, 304) = 4.54$, $p < .01$, is probably due to the nonmonotonicity of the RTs for stars. Nonetheless, the correlation between mean RT and dot position was .949, indicating that the relationship is reasonably linear.

The mean and standard deviation of the correlations between RT and ordinal dot position were .701 and .431, respectively, indicating that the relationship between these variables was approximately linear. Therefore, linear regression slopes and intercepts were computed to represent subtraction efficiency. The mean RTs used to compute slope and intercept were highly reliable, mean alpha = .899. The mean and standard deviation of the regression slopes were 598.8 and 528.0 msec/dot, respectively. The mean and standard deviation of the intercepts were 1.711 and .155 sec, respectively.

Integrate Task

Integration of image parts into a whole image is similar to the add and subtract processes, requiring operation of the Find and Put functions. Efficiency of this subprocess was measured in the Integrate task. The task was similar in several respects to the Add and Subtract tasks. In each problem a series of pictures was presented. Subjects were asked to mentally fuse the shapes presented in the picture series to form a new, whole image. The success of executing the desired fuse or integrate operations on

the image was evaluated by having subjects choose, from a set of pictures, that picture which depicted the result of the operations. As in the Add and Subtract tasks, subjects controlled the pace of the task by pressing a response button when ready for the next picture. The time allocated to each picture and accuracy at identifying the integrated image were measured.

Method

Materials. Two practice problems and 12 test problems were constructed in the same manner. In each problem five pictures of outline forms, such as the example in Figure 6, were presented. In the first picture of each problem the outline was partly blue, partly red, and partly green. In some problems, a fourth part of the outline was black. The next three pictures of each problem showed a different outline form to be integrated with the first picture. In these three pictures one form was blue and black, one red and black, and one green and black. The red, green, or blue part of each form matched the part of the original form of the same color. The order of the three colors varied for different problems. The fifth picture showed four outline forms labelled 1 to 4. Only one of these forms was the outline of the shape which would result from fusing the four previous forms as indicated by the colors. The other three forms were distorted in the area of either the blue, red, or green portion of the outline in the first picture; the location of the distortion was different for each distractor outline. The target (correct) outline appeared with the labels 1, 2, 3, and 4 in this last picture an equal number of times. All pictures were separately photographed on slides and appeared as black and color line drawings on a white background. The average height of the first four pictures of a problem subtended a visual angle of approximately 5.5 degrees.

Procedure. The procedures of the Integrate, Add, and Subtract tasks were identical in terms of control of slide advancement, the recording of subjects' responses, and the feedback given on each response. In addition to instructions regarding these aspects of the procedure, subjects were told:

> In this next set of problems, the first slide you'll see for each problem will be similar to this one here [first practice slide shown]. The first slide for each problem will look like this slide in that the outline shown will have a blue part, a red part, a green part, and sometimes, but not always, a black part. After this first slide, you'll see a series of three slides -- one blue, one red, and one green. Now, what I want you to do in this task is to imagine putting the figures you see on the slides together as you might do with a set of jigsaw puzzle pieces. For example, notice the shape of the blue part of the outline on this first slide. Okay? Now, see how that shape matches the shape of the blue portion of the outline of this figure? [second practice slide shown ... first and second slides presented back and forth until subject recognizes the match] Imagine fusing the two figures where their colors are the same.

> Okay, now notice how the red and green portions of the outline look [first practice slide shown again]. See how these pieces fit with the original shape as indicated by the colors? [third and fourth practice slides shown] Now, the last slide for each problem will show four figures. Your task is to decide which of these four figures is the outline of the shape that results from fusing all the the figures you've seen [fifth practice slide shown].

Each subject completed two practice problems and 12 test problems.

Results

This task proved to be quite difficult for our subjects. The mean proportion correct averaged over all subjects and problems was only .68. Proportion correct proved to be moderately reliable, alpha = .655.

The mean time between slides was 3.82 secs. Interestingly, the mean time decreased as more pieces were added. The slide viewing times were 4.20, 4.01, and 3.25 secs for the second, third, and fourth slides, respectively. A repeated measures Analysis of Variance established that the effect of slide position on viewing time was highly significant, $F(2, 156) = 25.53$, $p < .001$. The reason for this decrease in viewing time is unclear.

The mean and standard deviation of the correlations between slide viewing time and ordinal slide position were -.627 and .555, respectively. Because of this indication of a linear relationship between time and position, linear regression slopes and intercepts were computed. The mean and standard deviation of the slopes were -473.3 and 719.0 msec/slide. The mean and standard deviation of the intercepts were 4.772 and 2.28 secs, respectively. The mean viewing times upon which the slopes and intercepts were based proved highly reliable, mean alpha = .830.

Scan Task

In Kosslyn's theory (Kosslyn et al., 1979, Kosslyn, 1980) an image is scanned by means of an image transformation process. Kosslyn (1978) had found that possible sizes of an image are limited, and that the greatest resolution of an image is provided at a small, central region. Thus, inspection of a portion of an image often requires translating the image or, equivalently, scanning across the image to bring the attended portion into the region of greatest resolution.

The scanning process is a necessary component of many imagery tasks. Clearly, it is required when accessing information from a remote portion of an image. However, it may even play an important role in the tasks we have used to measure other basic processes. For example, when images are integrated scanning may be required to bring the image boundaries into central focus. Similarly, central focus achieved by scanning could be required when adding or subtracting detail in an image.

Kosslyn, Ball, and Reiser (1978) developed the method used to study scanning in this task. First, subjects were required to memorize a map of an island with several prominent landmarks. Then subjects were asked to scan from one landmark to another in the image. The time to complete this subjective scan was found to increase linearly with the distance between the landmarks on the map. In this task we used the same stimuli and method employed by Kosslyn et al. (1978). The function relating scanning time to distance was determined for each subject. The slope of this function should provide a measure of the efficiency of the scanning process.

<u>Method</u>

<u>Design</u>. A black-and-white drawing of a fictional island was copied after the island used by Kosslyn et al. (1978). There were seven objects on the island: a hut, grass, sand, a rock, a well, a tree, and a pond. A small red dot was drawn on each of the seven objects. The dots on the seven objects were located on the island such that the distance between pairs of dots varied from 2.1 cm to 20.7 cm.

A list of 21 object pairs was constructed by pairing each object with every other object. The ordering of objects within pairs was randomly determined with the constraint that each of the seven objects was first in half the pairs in which that object occurred. A list of 14 additional pairs was constructed by pairing the seven objects with six other objects that did not appear on the island (e.g., a church). The first member of these pairs was always an object on the island (all seven objects were in 2 of the 14 pairs).

These 35 pairs were recorded on tape with five seconds between first and second pair members and ten seconds between the second member of a pair and the first member of the next pair. The order of pairs on the tape was randomly determined with the constraints that no object could occur twice within three consecutive pairs, there could be no more than four island-island pairs in a row, and no more than three island-non-island pairs in a row.

In addition to these 35 pairs, a list of ten pracice pairs was constructed. These practice pairs were comprised of well-known U.S. cities (city-city pairs and city-non-city pairs). The pracice materials were recorded on the tape at the same rate of presentation as the experimental pairs.

<u>Procedure</u>. First, subjects were told that they must learn the layout of a fictional island. A drawing of the island was shown to them, and the seven objects and their names were pointed out. Subjects were told that, in particular, they should learn the locations of, and spatial relationships among, the red dots on the objects. Subjects studied the island for as much time as they desired, and then were asked to draw and label the dots on a picture of a blank island (the island without any of its objects). Subjects repeatedly studied and drew the dots until all

seven dots were placed within .5 cm of the actual locations.

At this point in the procedure, the task itself was described to the subject as follows:

> What you're going to be doing in this task is listening to a tape. On this tape you'll hear pairs of objects named, for example, hut-tree...well-hill, and so on. While you're listening to the tape, I want you to have a picture or image of the island in your mind. When you hear the first member of a pair, imagine focusing on the location of the dot for that object on the island. Now, the second member of each pair may or may not be one of the seven objects on the island. If it's not, say it's "chair" or "baby," simply press the button in your left hand right away. If it is one of the objects on the island, then imagine a black speck travelling in a fast, straight line from the first member to the second member of the pair. When the black speck arrives at the second object, press the button in your right hand.

The instructions were repeated and any questions were answered. The subject was told there would be some practice pairs first and that these would consist of names of U.S. cities, so to mentally picture a map of the U.S. At the end of the practice, the subject briefly studied the map of the island again. During the task, the experimenter started the computer's timer by pressing a button simultaneously with presentation of the first member of a pair, and the subject stopped the timer when he/she pressed a button after hearing both pair members. The five second interval between pair members was subtracted from all the response times.

Results

Mean RT averaged over all subjects is shown in Figure 7 as a function of distance between the objects on the map. These nomothetic results replicate the findings of Kosslyn et al. (1978). Mean RT increased approximately linearly with distance, as confirmed by a correlation of .682 between mean RT and distance.

The results for individual subjects were not in such complete agreement with theory. The correlation between mean RT and distance was computed for each subject. The mean correlation was only .278, and this correlation was quite variable over subjects; the standard deviation of the correlation was .345. Despite the low average correlation, linear regression slopes and intercepts were computed to represent the scanning efficiency of each subject. The mean and standard deviation of the slopes were 52.8 and 83.7 msec/cm, respectively. The mean and standard deviation of the intercepts were 6.56 and .88 sec, respectively.

Basic Task Intercorrelations

The correlations between measures of basic task performance are presented in Table 5. The diagonal of the correlation matrix

contains the communalities of all variables except the slope and intercept of RT for the Rotation Task. These communalities were determined by Principal Axis Factor Analysis. The slope and intercept from the Rotation Task were excluded from this analysis because these statistics were computed for only 52 subjects. The correlations and communalities presented in Table 5 are based on data from 77 subjects.

The Principal Axis Factor Analysis identified five factors with corresponding eigenvalues that exceeded one. Varimax rotation yielded ready interpretations of the five factors. The first factor was identified by the number correct in each task, particularly the Add and Subtract Tasks. The factor loadings were .51 for the Rotation Task, .77 for the Add Task, .84 for the Subtract Task, and .51 for the Integrate Task. There were no other loadings greater than .4 for this factor.

The second factor corresponded to the slopes for the Add and Subtract Tasks. The factor loadings were .86 for both tasks, and there were no other loadings greater than .3 for this factor. The intercepts for the Add and Subtract Tasks defined the fourth factor. The loadings were .69 for the Add Task and .86 for the Subtract Task. No other loadings exceeded .22 for this factor. It is encouraging that the slopes and intercepts corresponded to different factors. The slopes and intercepts were calculated from the same data, resulting in an operational dependency that inflates the correlations between these measures. Such biases in the correlations would tend to produce a single factor for both the slope and intercept.

The third factor corresponded to the slope and intercept of the Integrate Task. The loadings were -.86 for the slope and .90 for the intercept. No other loadings exceeded .16 for this factor. Thus, for the Integrate Task the slope and intercept did not measure distinct abilities. The last factor corresponded to only a single variable, the intercept for the Scan Task. The loading was .82 for this intercept and no other loading exceeded .28. Two variables, mean RT in the Picture Task and the intercept for the Scan Task did not have loadings greater than .4 on any factor.

We conclude that the Add and Subtract Tasks measure equivalent sources of individual differences. The accuracies, slopes and intercepts from these two tasks established three separate factors, though the accuracy factor included moderate loadings for accuracy in other tasks. Given the high correlations between the two tasks for each measure, it is clear that no important information about individual differences would be lost by computing composite measures of accuracy, slope and intercept for the Add and Subtract Tasks. These three composite measures were computed by summing the standardized measures for each task. The correlation between the resulting slope and accuracy measures was highly significant ($r = .48$). The slope measure was intended to measure the efficiency of basic processes, but a low slope could arise from efficient processes or random responses. To eliminate this confounding, the linear effect of accuracy on the

Add and Subtract slope was removed.

The third factor indicated that the slope and intercept for the Integrate Task also measured equivalent sources of individual differences. Thus, these measures were replaced with the mean RT for that task. The correlations among these composite measures, the slope and intercept from the Rotate Task, the mean RT for the Picture Task, the Scan Task intercept, and accuracy for the Rotate and Integrate Tasks are presented in Table 6.

SELF-REPORT TESTS

One of the earliest self-report tests of mental imagery was the 150-item Questionnaire upon Mental Imagery introduced by Betts (1909). Betts' questionnaire measured the vividness of imagery in every sensory modality. This test was later shortened to 35 questions by Sheehan (1967), and is known in this shortened form as the QMI. The QMI remains the most widely used measure of imagery vividness. It measures vividness in seven sensory modalitities, and factor analyses suggest these measures are partly independent (Sheehan, 1967). Recently, Marks (1973) devised a 16-item questionnaire of visual vividness called the Vividness of Visual Imagery Questionnaire (VVIQ). The VVIQ has received wide usage only during the last few years.

Self ratings on these tests of vividness have been compared with performance in paired-associate learning, recognition memory, free recall, the speed to generate an image, speed to mentally rotate a figure, and speed to discriminate between two slightly different pictures (see Ernest, 1977 for a review). For the most part, vividness is unrelated to performance in these tasks. Vividness is apparently related to memory performance for verbal stimuli only when the memory test is unexpected (Janssen, 1976; Sheehan, 1973). Perhaps individuals with vivid imagery are more likely to encode the stimuli in images when no test is expected.

Marks (1973) found a relationship between vividness measured with the VVIQ and recall of pictures, but no relationship was found with the QMI (Sheehan & Neisser, 1969). Gur and Hilgard (1975) found that vividness measured with the VVIQ correlated with the speed to discriminate between pictures, but Berger and Gaunitz (1977) disconfirmed this finding and attributed the original result to demand characteristics. Finally, Snyder (1972) found no relation between speed of mental rotation and vividness.

In contrast to these negative findings, Ernest and Paivio (1969) found that people with vivid imagery are quicker to generate an image, particularly for abstract words. This finding suggests a relationship between vividness and the basic Picture function proposed by Kosslyn. However, the research relevant to learning consistently finds little or no relationship to vividness.

The test used in virtually all studies of imagery control is the Gordon Test of Visual Imagery Control (TVIC) (Gordon, 1949).

This test was modified slightly by Richardson (1969) to include 12 questions. Unlike vividness ratings, imagery control ratings have proven to be strongly related to measures of cognitive functioning. For example, control was correlated with paired-associate learning (Morelli & Lang, 1971), speed of mental rotation, speed of spatial problem solving, and performance on other spatial tasks (Snyder, 1972).

Paivio (1971) developed a test to discriminate between visualizers and verbalizers called the Individual Differences Questionnaire (IDQ). Recently, Richardson (1977a) has modified the IDQ to produce a shorter test containing 15 questions called the Verbalizer-Visualizer Questionnaire (VVQ). The tests have not been widely used, and most studies with these tests have examined their psychometric properties.

In this study self-rating questionnaires were given to assess vividness, control, and preferences. Vividness was assessed by the VVIQ developed by Marks, imagery control was assessed by the TVIC developed by Gordon, and preferance for visual or verbal strategies was assessed by the VVQ developed by Richardson. We expect imagery control to be related to the transformation and integration functions, because it is these functions that provide image control within Kosslyn's model. Vividness may be related to the Picture function, but is not expected to be related to other basic processes. The inclusion of the preferance questionnaire was exploratory.

All three self-rating questionnaires were given, one at a time, at the beginning of the group session. Subjects read the instructions accompanying each questionnaire, and the experimenter reviewed the instructions and answered any questions. Subjects were allowed as much time as they wanted to complete each questionnaire.

Results

Vividness

For the VVIQ a rating on a 5 point scale was provided by each subject to each of the 16 items. The mean rating for each subject provided a measure of imagery vividness; the higher the rating, the less vivid the imagery. The mean rating averaged over subjects was 2.32 and the standard deviation of the mean ratings was .562. The reliability of the mean ratings, alpha = .828, was about the same as the reliability obtained by Marks (1973).

Visualizer/Verbalizer

For the VVQ each of 15 questions was answered by marking true or false. These answers were assigned values of one or zero such that one corresponded to a response of a visualizer and zero corresponded tc a response of a verbalizer. The sum of these values represents the degree to which a subject preferred the cognitive style of a visualizer. The mean score averaged over

subjects was 9.44 and the standard deviation of the scores was 2.21. The visualizer/verbalizer scores had low reliability, alpha = .524. Indeed, this reliability is notably lower than the test-retest reliabilities of about .9 obtained by Richardson (1977a).

Control

For the TVIC each of 20 questions was answered by marking yes, no, or unsure. A no response was assigned the value zero, an unsure response was assigned the value one, and a yes response was assigned the value two. The sum of these values over the 20 questions represents the amount of control over imagery that a subject reports experiencing; the higher the sum, the greater the reported control of visual imagery. The mean score averaged over subjects was 20.09 and the standard deviation was 3.72. The scores were moderately reliable, alpha = .707.

Intercorrelations

Scores on the Verbalizer/Visualizer Questionnaire were uncorrelated with scores on the vividness test ($r = .013$) and the Test of Visual Imagery Control ($r=.045$). However, subjects who reported more vivid imagery also tended to report more control over their imagery, resulting in a negative correlation between scores on the TVIC and VVIQ, $r = -.329$, $p = .002$. This result is consistent with previous research using other scales of vividness and control (e.g., Morris & Gale, 1974; Starker, 1974); greater vividness is associated with greater control.

The relationship was weak between these self-report measures and performance on basic imagery tasks. Stepwise multiple regressions were computed to attempt to predict self-reports from linear combinations of basic task performance. VVIQ responses were not significantly correlated with any measures of basic imagery processes ($p > .05$ for all measures).

VVQ responses were significantly correlated ($p < .05$) with the Add and Subtract slope, $r = -.245$, the Rotate slope, $r = -.291$, and the Rotate intercept, $r = -.285$. When the Rotate linearity measures were excluded from the analysis the only variable with a significant beta weight was the Add and Subtract slope. Inclusion of the Rotate measures eliminated the Add and Subtract slope from the equation. The multiple correlation was .43 between the VVQ scores and a linear combination of the Rotate slope and intercept. Thus, it appears that self-reports of being a visualizer are weakly related to the efficiency of basic imagery transformations.

TVIC responses were significantly correlated only with the number correct on the Integrate Task ($r = -.242$). Thus, the greater control a subject reported, the more errors that subject was likely to make in the Integrate Task. We doubt that this correlation represents a real or interesting relationship, and conclude that self-reports of imagery control are unrelated to the basic imagery processes we have measured.

SPATIAL ABILITY TESTS

Tests of spatial ability frequently seem to measure many of the same processes postulated by Kosslyn as basic to imagery. For example, embedded figures tests require decomposition of an image, figural rotation tests require mental rotation, and tasks such as paper folding require a combination of such basic functions. Several such standard spatial ability tests developed for use in intelligence research were administered. If performance on these tests depends on basic processes as hypothesized, then spatial ability tests that require the same processes should be correlated. Furthermore, performance on the spatial ability tests should be reasonably predictable from basic imagery process measures.

All the spatial ability tests were conducted in essentially the same manner. Subjects read the instructions accompanying each test, the experimenter reviewed the instructions and answered any questions, then subjects were given a specified period of time to complete the test. Subjects were encouraged to complete as many problems as possible in the allotted interval. No instructions were given to encourage or discourage guessing. All the standard tests except for the Space Relations Test were given in the group session.

In addition to the standard tests, new tests were developed that were expected to require combinations of the basic imagery processes. Subjects were required to assemble portions of a jigsaw puzzle, a task which appears to require mental rotation and integration of images. Another task required subjects to follow a specified path out of a maze, but the specified path was rotated so that subjects would have to perform mental rotations.

Designs Test

The Designs Test was developed by Thurstone (French, Ekstrom, & Price, 1963). This test was presented on three pages, each containing 100 figures. The task required identification of those figures which contained a model figure, the upper case Greek letter sigma. Subjects simply marked those figures which contained the model. No subject was able to finish in the 3 minutes allotted for this test.

To solve the problems of the Designs Test, the model and test figures must be compared. The model figure included four line segments in a particular orientation. The Find function could be used to examine the test figure and determine whether the line segments are present. Alternatively, the Put function could be used to subtract extra segments from the test figure in an attempt to achieve a match between the test figure and model.

Results

In all discussions of spatial ability test results the word "response" is intended to refer only to overt responses. Thus, only problems that were marked could be counted as correct or

incorrect responses. Problems that were correctly not marked were not counted. Problems that should have been marked, but were not, were counted as incorrectly omitted responses.

The means, standard deviations, and reliabilities of the number of correct and incorrect responses are presented in Table 7. The mean, standard deviation, and reliability of the number of incorrectly omitted responses were 2.82, 3.64, and .772, respectively. Because subjects were unable to complete this test in the allotted time, omitted responses were not counted beyond the last overt response. The reliabilities of these measures were estimated by application of the Spearman-Brown formula to correlations of performance on odd and even numbered problems.

The low number of errors indicate that speed rather than power was tested. Subjects made few of the possible 40 correct responses. Because error rates were so low, little was to be gained by including these scores in further analyses or by computing a score corrected for guessing. Thus, only the number of correct responses was retained for further analyses.

Figures Test

The Figures Test was similar to the Rotate Task used to measure the Rotate basic function, and therefore should depend largely on that transformation function. The test included only 10 problems, each consisting of a model figure and a row of six test figures. All seven figures were line drawings of two-dimensional objects. The task required determining which test figures were the same as the model figure but rotated in the plane of the page. Distractor test figures were rotated mirror images of the model. The number of test figures that were the same as the model varied from one to three per problem. Only a few subjects completed this test in the allotted 3 minutes.

Results

The means, standard deviations, and reliabilities of the number of correct and incorrect responses are presented in Table 7. The mean, standard deviation, and reliability of the number of incorrectly omitted responses were 2.51, 3.62, and .819, respectively. Again, omitted responses were not counted beyond the last overt response, and reliabilities were estimated from split-half correlations. The maximum possible number of correct responses was 26. Because the number of incorrect responses was reliable, a correction for guessing was applied. The score for each subject was defined as the number correct minus half the number of incorrect responses. The mean and standard deviation of this score were 19.90 and 6.29, respectively.

Paper Folding Test

Each of the 20 problems on the Paper Folding Test (French, Ekstrom, & Price, 1963) involved determining the appearance of a square piece of paper after it had been folded in certain ways, had a hole punched through it, and been completely unfolded.

For each problem a series of pictures indicated how the paper was to be folded and where the hole was to be punched. To the right of these pictures were a set of five test figures. Each test figure was a square with one or more holes; only one of these test figures corresponded to the unfolded piece of paper, and the subject's task was to determine which one. Only a few subjects completed all 20 problems of this test in the allotted 5 minutes.

The Paper Folding Task requires many of the basic imagery functions. Mentally folding the paper is a transformation similar to rotation. Punching the hole requires the Find and Put functions. Unfolding the paper and locating the position of the holes after each stage requires additional use of the Rotate transformation, Find, and Put functions. The image must be continually refreshed, possibly involving the Picture function. Even the Scan function could be involved to locate the relevant regions at each stage.

Results

The means, standard deviations, and split-half reliabilities of the number of correct and incorrect responses are presented in Table 7. The Paper Folding Test proved difficult for our subjects; the mean number of correct responses was only about half the 20 problems. Because of the low reliability of the number incorrect, the number of correct responses was not corrected for guessing.

Components Test

The Components Test (Flanagan, 1953) was similar to the Designs Test, but was much more difficult. As in the Designs Test, subjects must search for model figures embedded within test figures. However, in this test, there were five model figures and one of the five models was embedded in each of 21 test figures. The task required deciding which model was embedded in each test figure. Both the model and test figures were line drawings of abstract shapes, and the test figures were extremely complicated. Only a few subjects answered all 21 problems in the allotted 7 minutes.

Solving the Components Test requires comparisons of the model and test figures, just as for the Designs Test. We expect the Find and Put functions to be primarily involved in this process.

Results

The summary statistics for this test are presented in Table 7. Subjects found the components task quite difficult. On the average, only about half of the 21 problems in this test were answered correctly. However, subjects made few overt errors. Because of the low reliability of the error score, no correction for guessing was applied. Thus, number correct was the only score used to represent subjects' ability in this task.

Space Relations Test

The last test given in the individual session was Form A of the Space Relations Test (Bennett, Seashore, & Wesman, 1947). Each problem of this test requires mentally folding a flat figure in specified ways to construct a three-dimensional object. The imaged object is compared with line drawings of three-dimensional objects to determine which are equivalent to the imaged object. Thus, the task might require use of the Scan, Rotate, and Find functions, as well as comparison operations.

Each problem consisted of a drawing of a flat figure with lines indicating where the figure was to be folded. To the right of the figure were drawings of five three-dimensional objects in various spatial orientations. The task was to identify the drawings that correspond to the folded figure. For each problem zero to five objects could be equivalent to the figure. No subject finished all 40 problems of this test in the allotted 10 minutes.

Results

The summary statistics for this test are presented in Table 7. Because of the high reliability for incorrect responses, a correction for guessing was applied. The score for each subject was the number correct minus half the number of incorrect responses. The mean and standard deviation of this score were 38.43 and 12.9, respectively.

Cube-Cutting Test

The Cube-Cutting Test was adapted from Richardson (1977b). This test consisted of four questions pertaining to a colored cube. Before starting the test, the cube was drawn on a blackboard and described to subjects. The description was as follows:

> I want you to imagine a cube [experimenter draws a cube on the blackboard] composed of a white substance on the inside and painted red on the outside. Each side of this cube is three inches long [experimenter labels the sides 3"]. Now, imagine making six cuts in this cube [experimenter shows where cuts are made] so that we end up with 27 smaller cubes, each 1" x 1" x 1". On the piece of paper that you have, there are some questions about these 27 small cubes. In answering these questions, you are not allowed to draw pictures -- you'll just have to picture the cube in your mind.

The experimenter then erased the blackboard, and subjects read and answered four test questions. The questions were: (1) How many cubes have three faces painted red?; (2) How many cubes have two faces painted red?; (3) How many cubes have one face painted red?; and (4) How many cubes have no faces painted red? Most subjects were able to provide an answer to all four questions in the 4 minutes allotted for this test.

The Cube-Cutting Test requires subjects to maintain a clear

image while examining the image from different perspectives. We expected this task to require three basic functions: (1) the Picture function to generate and maintain the image; (2) the Rotate function to manipulate the viewing perspective; and (3) the Scan function to move to different locations in and on the cube.

Results

The mean, standard deviation, and reliability of the number of correct answers are presented in Table 7. Cronbach's coefficient alpha was calculated as the reliability estimate for this test. Averaged over subjects, the proportions of correct responses to the four questions were .701, .403, .636, and .662, respectively. Only the total number of correct responses was retained for further analyses.

Puzzles Test

It is a challenge to find familiar tasks that require use of imagery or spatial ability. One such task is the common jigsaw puzzle. A jigsaw puzzle requires determining which pieces have complimentary outlines. We expect the Rotate, Find, and Put functions to be required by this task. Typically, pieces must be rotated, mentally or physically, to match the orientations of candidate pieces. Following rotation, identification of the matching pieces requires integration of the piece outlines, accomplished by the Find and Put functions.

Method

Materials. Five jigsaw puzzles were constructed, including one practice and four test puzzles. Each puzzle consisted of nine jigsaw puzzle pieces which fit together to form a three-by-three matrix. Because the nine pieces were chosen from the interior of a large jigsaw puzzle, the outline of each completed puzzle was irregular (non-rectangular) in shape. The pieces were all upside-down so their color would be a uniform gray. The edges of puzzle pieces which comprised the outline were colored red; thus, a completed puzzle was gray with a red border.

Procedure. Each puzzle was presented with the nine pieces in a random arrangement that was constant for all subjects. The instructions explained that the red border defined the outside edge of the puzzle, and emphasized the importance of solving the puzzle mentally. That is, subjects were instructed to avoid using a trial-and-error approach to connect puzzle pieces. They were encouraged to decide that two pieces fit together by visual inspection before actually attempting to join them. A practice puzzle and four test puzzles were completed. For each puzzle, the experimenter started a stopwatch when the puzzle was presented to the subject, and stopped the stopwatch when the puzzle was completed.

Results

The mean completion times for the four puzzles were 106.9, 82.0, 100.9, and 81.5 secs. To measure the facility of each subject at puzzle completion, the mean of the four completion times was computed for each subject. These means were reasonably reliable, alpha = .737. The mean and standard deviation of the subject means were 92.8 and 36.4 secs, respectively.

Mazes Test

Another familiar task requiring use of imagery or spatial reasoning is reading maps. Map reading requires recognition of the correspondence between a physical layout and a representation (the map) of that layout. Following a route marked on a map may require repeated physical or mental rotations of the map to achieve a correspondence with the physical layout.

The Mazes Test was developed to simulate the processes involved in finding a route marked on a map. Complex printed mazes and, on a separate page, rotated solutions through the mazes were presented. The test required drawing the indicated path through the maze. Thus, subjects were required to mentally rotate and integrate images.

Method

Materials. Five mazes, one practice and four experimental, were selected from a book of mazes. Each maze was a line drawing with one point labelled "start" and another labelled "finish." The solution for each maze (a line connecting the "start" and "finish" points) accompanied the maze on a separate piece of paper; the solution sheet did not include a drawing of the maze itself. Every solution was rotated (relative to the maze itself) between 0 and 90 degrees, and the side of the solution corresponding to the top of the page on the maze was labelled "top" so that subjects could see how the solution had been rotated.

Procedure. The task required drawing a continuous line from "start" to "finish" without crossing any lines on the maze. The instructions emphasized that subjects were not to use their usual strategy for solving mazes, but were to follow the route shown on the solution much as they would follow a map. The rotation of the solution relative to the maze was explained to subjects.

Each subject completed one practice and four test problems. The subject was timed with a stopwatch from the time the maze and its solution were presented until the subject reached the "finish" point. The experimenter watched the subject while he/she worked and required correction of any illegal moves (crossing a line on the maze) when they occurred.

Results

The mean times to complete the four test mazes were 133.0, 139.9, 49.7, and 105.3 seconds. To measure ability at maze completion, the mean of the four completion times obtained by each

subject was computed. These means were reasonably reliable, alpha = .665.

Intercorrelations

The intercorrelations among the spatial ability task measures are presented in Table 8. A Principal Axis Factor Analysis determined the communalities listed on the diagonal of the correlation matrix in Table 8. The factor analysis identified only one factor with a corresponding eigenvalue greater than one. Performance on all tasks was correlated, with correlations ranging in absolute value from .35 to .65. The single factor accounted for 50 percent of the common variance among the task measures. Thus, there is no evidence in the intercorrelations to suggest the existence of separate imagery abilities such as those postulated.

More precise tests of the predicted relationships between performances on spatial ability and basic imagery tasks were conducted by computing multiple linear regressions to predict spatial ability performance from basic task performances. The regressions were computed both including and excluding the slope and intercept from the Rotate Task. These measures were excluded from one analysis because they were available for only 50 of the subjects who completed the spatial ability tests. Thus, in one analysis only accuracy was available as a measure of the effectiveness of the rotation process. The measures with significant beta weights and the multiple correlations are presented in Table 9 for the two sets of analyses.

We predicted that image rotation would be required in six of the tasks: Figures, Paper Folding, Space Relations, Cube-Cutting, Puzzles, and Mazes. This prediction was supported by inclusion of rotation accuracy in the regression equation for all the predicted tasks except for Mazes. However, rotation accuracy unexpectedly was included in the equations for the Components and Designs Tests also. In fact, rotation accuracy was correlated significantly with performance in every spatial ability test, including Mazes ($r = -.347$ for Mazes). Perhaps rotation accuracy is a sensitive measure of the effectiveness of all image transformations.

Inclusion of the Rotate linearity measures established the particular importance of rotation in the Figures and Space Relations Tests. The Rotate slope was included in the regression equation for these two tasks. Interestingly, Rotate intercept was included in the equations for four of the spatial ability tests.

All of the spatial ability tests except for Figures were hypothesized to require use of the Find and Put functions. These functions were not measured directly, but were presumed to be measured by a combination of the Integrate, Add, and Subtract Tasks. Reaction time for the Integrate Task was included in the regression equation for all the predicted tests except for Components, Designs, and Puzzles. In addition, both Components and

Puzzles performances were significantly correlated with Add and Subtract accuracy (r = .36 and r = -.35, respectively) and Puzzle performance was significantly correlated with the Add and Subtract intercept (r = .36). Thus, only the Designs tests failed to show the expected relationships.

Surprisingly, the Figures Test also was correlated with measures of the Find and Put functions. Both the Integrate reaction time and the accuracy of the Add and Subtract Tasks were included in the regression equation for the Figures Task. It is unclear how this task might require these functions.

We hypothesized that Picture and Scan processes might play an important role in some of the spatial ability tests. The Picture function is particularly important in the Cube-Cutting Test because a physical picture was not available to the subjects as they performed this task. This prediction of a relationship with performance in the Picture Task was confirmed for the Cube-Cutting Test, but not for the Paper Folding Test in which a physical picture was available. Surprisingly, performance in the Components Test was significantly correlated with Picture performance too (r = -.28). Performance on the Scan Task (slope and intercept) was not significantly correlated with performance in any of the spatial ability tests. Perhaps this test did not provide a valid measure of the scanning process as it is used by subjects in complex imagery tasks. The Scan Task required subjects to imagine a black dot moving from one location to another in an image. Perhaps subjects are able to shift perspective more rapidly when this requirement is removed.

MEMORY TESTS

The existence of a link between imagery and memory performance has been recognized for thousands of years. The Ancient Greeks used mnemonic devices that depend on imagery to organize and remember speeches and stories. If properly used, a mnemonic device permits a person to achieve phenomenal memory performance. However, it is noteworthy that such mnemonic devices are not widely practiced. Apparently, the devices are not strategies that people are likely to develop independently, and the devices are often difficult to apply to the information presented in educational settings.

It remains unclear whether imagery influences memory performance for individuals who have not been trained in the use of mnemonic devices. Paivio (1971) found that words that readily evoke images are better remembered, suggesting that imagery vividness is a determinate of memory performance. However, it is possible that some other characteristic of words, such as familiarity or frequency, is the cause of both the memory performance and the imagefulness of the words.

If, as Paivio suggested, imagery strongly influences memory performance, than one would expect memory performance to be correlated with some characteristic of imagery use. This hypothesis has motivated many studies of the relationship between

various aspects of imagery and memory performance. Surprisingly, self-reports of imagery vividness have proven uncorrelated with memory performance for the most part (see Ernest, 1977 for a review). However, self-reports of imagery control have been found to be correlated with performance on tests of learning and spatial ability. Unfortunately, it is unclear whether this finding should be interpreted as confirmation of Paivio's view, or as evidence for a general ability factor that influences imagery and memory.

A predisposition to use imagery is a third factor that has recently been studied (Richardson, 1977a). Individuals who prefer a visual or imagery mode of thought to a verbal mode of thought could be expected to show better memory performance because they would naturally adopt an imagery mnemonic. Surprisingly, we know of no studies that have examined the relationship between memory performance on this cognitive style variable.

The development of cognitive psychology has led to a new approach to the study of the relationship between imagery and memory. Bower (1972) and others have studied the characteristics of images that are associated with good memory performance. The major finding of this research is that images that associate two or more words, such as in cued recall, are most effective if the images represent a dynamic relationship between objects. This finding suggests that subjects who produce more dynamic images will remember more words. Perhaps the correlation between imagery control and memory performance is explained by this finding; subjects with greater imagery control produce more dynamic images and therefore remember more. We expect imagery control and the ability to create dynamic images to depend on ability to use imagery transformations such as scan, integrate, and rotate.

Two memory tests were administered. First a free recall test was given in which half the words were concrete and half were abstract. An imagery strategy should be appropriate for memorization of the concrete words, but should provide little or no advantage for the abstract words. A cued recall test was given in which all the items were concrete. The use of concrete words was intended to facilitate the use of an imagery strategy. If subjects use an imagery strategy then relationships can be expected between memory performance and basic theoretical functions. Relationships are expected with self reports of imagery control also.

Free Recall Test

Method

Materials. Four lists of ten words were constructed. Half of each list was comprised of abstract words, and half of concrete words. All of the abstract words were rated low on the dimensions of imagery and concreteness in the Paivio, Yuille, and Madigan (1968) norms; all of the concrete words were rated high on these dimensions in the norms. A fifth practice list was constructed in the same manner. All five lists were then recorded

on tape; the order of words within each list was randomized, and the rate of presentation within a list was one word every three seconds.

Procedure. The 10 words of each list were presented followed 3 seconds later by the words "end of list." Subjects were allowed 1 minute to write all the words they could remember from that list. The instructions emphasized that the words could be reported in any order.

Results

Proportion correct is presented in Figure 8 as a function of the serial position of the list items. Although the results appear quite variable, the typical serial postion effect, including both primacy and recency, are apparent. Unfortunately, it is impossible to examine the serial position effects for abstract and concrete words because the two classes of stimuli were not presented equally often at each position.

As expected, concrete words were recalled more frequently than abstract words, but the difference was surprisingly small. Over the four lists the mean number of words recalled was 13.9 concrete words and 12.2 abstract words. The number of words of each class recalled was moderately reliable; alpha was .756 for concrete words and .704 for abstract words.

Cued Recall Test

Method

Materials. Two lists of 20 cue-target or stimulus-response pairs were constructed. All cues and targets were rated high on the dimensions of imagery and concreteness in the Paivio, Yuille, and Madigan (1968) norms. A third practice list of five cue-target pairs was constructed. All three lists were recorded on tape; the order of word pairs was randomized within each list and the rate of presentation was one pair every five seconds. Response sheets were prepared containing the cue words in the same order as in the presentation list, with spaces for the subjects to write the target words.

Procedure. Before each list was presented, a recall sheet was provided, but subjects were prohibited from looking at it until the end of the list. The tape was then started and subjects listened to the series of word pairs. Five seconds after the last pair, the words "end of list" were presented as a cue to read the recall sheet, and commence recalling as many of the targets as possible. Subjects were told that the cues on the recall sheet were intended as aids to memory, and that a given target did not have to be written next to its cue in order to be scored as correctly recalled. One minute was allowed for recall of the practice list and two minutes for recall of the two experimental lists.

Results

Figure 8 presents proportion correct as a function of serial position. In this figure target pairs were combined so the cued recall and free recall results can be compared. Thus, serial position i in the figure represents performance at serial position (2 x i) and (2 x i -1). Slight primacy and recency effects can be observed in Figure 8.

Over all serial positions the mean number of correct responses was 26.66 words from the 40 words presented. The standard deviation of the number of correct words was 9.22. The number of correctly recalled words proved to be highly reliable, alpha = .921.

Intercorrelations

Cued recall performance was correlated with free recall performance for both concrete and abstract words, $r = .460$ and $r = .396$, respectively. Furthermore, recall performance for concrete and abstract words was correlated, $r = .561$. With one exception, all correlations between measures of memory performance and self-report imagery measures were not significant. The exception was a significant correlation ($r = -.23$) between number of abstract words recalled and the VVQ. Thus, subjects who were verbalizers would tend to recall more abstract words. Surprisingly, the relationship between imagery control and memory performance noted by Ernest (1977) was not replicated in this subject sample.

If concrete words elicit a memory strategy that utilizes imagery as Paivio has suggested (1971), then one would expect performance on concrete and abstract words to show different relationships with imagery measures. The relationships between the measures of memory performance and basic task performance were examined using multiple linear regression. When Rotate linearity measures were excluded, recall of both concrete and abstract words was predicted by accuracy in the Add and Subtract Task. Performance for abstract words was also influenced by the sex of the subject, with women recalling more than men. When the Rotate linearity measures were included, recall of both abstract and concrete words were predicted by Rotate slope and accuracy in the Add and Subtract Tasks. The multiple correlations were .54 for the concrete words and .56 for the abstract words. These relationships suggest that imagery does play an important role in free recall, but the importance of imagery is substantial for both concrete and abstract words.

Performance in the Cued Recall Task showed a very different pattern of relationships with basic imagery task performance. The strongest predictor of Cued Recall performance was the sex of the subject ($r = .38$) with women recalling more than men. When the Rotate linearity measures were excluded, the Integrate reaction time and Rotate accuracy were added to the regression equation to achieve a multiple correlation of .52. Apparently, Cued Recall performance depends on the use of imagery too, but depends less on the efficiency of the image transformation processes. The relationship with sex was totally unexpected.

DISCUSSION

The basic tasks in this experiment were designed for the purpose of assessing individual differences in subjects' abilities to perform basic imagery functions. It is difficult if not impossible, however, to isolate one particular basic process in a given task. For example, the Add Task undoubtedly requires scanning across the image to place or find dots and possibly requires enlarging or shrinking of the image while adding dots. While recognizing this problem, the basic tasks included in this experiment each focused on one basic function. Factor analyses provided evidence that the basic tasks tap different imagery functions; separate factors were identified corresponding to measures of different functions.

One of the main purposes of the present research was to explore the possibility that performance on memory, self-report, and spatial ability tasks could be predicted from basic task measures. Hypotheses as to the basic functions comprising each task were developed. In some cases, our hypostheses were supported by the data, whereas in other cases the results were rather surprising.

Self-Report Tests

As concerns the self-report measures, we were surprised to find that Gordon's (1949) Test of Visual Imagery Control (TVIC) did not correlate meaningfully with performance on any of the basic tasks. In this test, the subject is asked to generate and transform images in ways which would involve basic processes of image generation and transformation. For example, some test items request the subject to add detail to and rotate an image of a car. Although others have found a relationship between TVIC scores and spatial task measures (e.g., Morelli & Lang, 1971; Snyder, 1972), the lack of any correlation here might be attributed to a discrepancy between subjects' experience of image control and their objective degree of control.

Given the results of previous research, we were not surprised that the imagery vividness reported by subjects, as measured by the Vividness of Visual Imagery Questionnaire (Marks, 1973), was uncorrelated with all of the basic task measures. Although we might have expected a relationship between subjective vividness and speed of image generation (as measured by Picture latencies), we did not expect the VVIQ to correlate with any of the other basic task measures.

Indeed, the only self-report measure found to be correlated with any basic task measures was that of the Verbalizer-Visualizer Questionnaire or VVQ (Richardson, 1977a). Subjects reporting a preference for visually imaging rather than verbalizing were more efficient at imagery transformation (as indicated by these subjects' smaller slopes in the Add, Subtract, and Rotate Tasks).

The VVQ was also found to be negatively correlated with free

recall performance of abstract words. Perhaps subjects who reported using a verbal style of thinking were more likely to use a verbal strategy, rather than an imagery strategy, during encoding of the list of recall items. Similarly, the subjects who reported using a visualizing style of thinking might be more likely to use an imagery strategy. Abstract words are less easily imaged than concrete words, so verbalizers may have been more successful at remembering abstract words because they were able to use a more effective memory strategy.

Memory Tests

In addition to this relationship between free recall of abstract words and the VVQ, both cued and free recall performance were found to be associated with a subset of basic task measures. Particularly interesting is the inclusion in the regression equation for cued recall of Rotate accuracy and Integrate reaction time. Encoding of cue-target pairs as a composite image which integrates cue and target images is a very effective memory strategy in cued recall tests (Bower, 1972). The success with which subjects are able to mentally translate images (as in the Rotate Task) into position for composition, and the efficiency with which they are able to integrate two images (as in the Integrate Task) could conceivably affect the cohesion of the cue-target image. The greater the cohesion or integration of cue and target, the more effective the cue will be for retrieval of the target image.

Spatial Ability Tests

The results of the Spatial Ability Tasks were mixed. In some cases, our hypotheses as to the basic functions involved in a spatial task were supported by the data; in other cases, our hypotheses were not supported. One picture which emerges from the regression analysis on the spatial tasks (see Table 9) is that ability to rotate images (as measured by the Rotate Task) is a fairly good predictor of spatial ability test performance in general. With the exception of the Mazes Task, Rotate accuracy correlated positively with every spatial task, including both those expected and those not expected. Thus, although it is not immediately clear how, for example, the Designs Task involves image rotation, the Rotate and Designs Tasks tap some common imagery ability.

A combination of Add, Subtract, and Integrate Task measures were included in the regression equation for all but one of the spatial tasks where the Put function was expected. However, it is not clear in every case why a particular Put function measure entered into the prediction of a given spatial task measure. For instance, why should Integrate reaction time, rather than Add and Subtract measures, be related to Paper Folding scores? It would seem that visualizing the punching of a hole in a piece of paper is more like visualizing the addition of a dot to a base form than visualizing the fusion of two shapes. It appears that, at least for the tasks in this experiment, it is not possible to predict complex spatial task performance based on performance in

quite specific component tasks.

The regression analyses for the spatial tasks yielded a rather interesting result regarding Picture latencies. Picture latencies were entered only in the equations for Cube-Cutting and Components. Of the spatial tasks, only Cube-Cutting has no supporting pictures drawn on the test paper. Even though most or all of the spatial tasks require maintenance and refreshing of images, the subject is able to refer to the objective picture as often as desired. In the case of Cube-Cutting, however, once the test actually begins, the image of the cube must be generated and maintained without visual support of a picture.

Problems

Although Rotate measures correlated with Cube-Cutting performance as expected, Scan measures did not. There are several posssible reasons for why the results were not completely as we had expected. First of all, a given basic task may not be a sensitive measure of the process it was designed to test. The Scan Task, for example, was not involved in the prediction of performance on any of the spatial tasks (see Table 9). Certainly, several of the spatial tasks require scanning of an image (e.g., in Paper Folding where the image of the unfolded piece of paper must be scanned to locate holes). The fact that Scan was not included in spatial task regression equations may simply be because this task was not a sensitive measure of subjects' efficiencies at scanning across an image.

A second and related possible reason for the negative results may be that a given basic task assessed abilities specific to that particular task and not abilities on the hypothesized basic process in general. Again, for example, mentally scanning from point to point on an imaged island may be different from scanning across an image of an unfolded piece of paper after several other processes have been carried out on that image.

Third, subjects may not have always carried out a basic task in the manner we assumed in developing the tasks. This seems especially possible in the case of Scan where there isn't much of a check on what subjects are doing, but may also be true for other tasks. For instance, although a particular strategy was encouraged in the Add Task (e.g., subjects were instructed to add each dot to their image of the base form), some subjects may have found a verbal strategy more effective while others may have used a different imagery strategy from the one we expected. Just as some subjects may not have been doing what we expected in a given basic task, it is not necessarily true that any or all subjects carried out the more complex tasks as we expected.

REFERENCES

Bennet, G.K., Seashore, M.G., & Wesman, A.G. Differential Aptitude Tests. New York: The Psychological Corporation, 1947.

Berger, G. H., & Gaunitz, S. C. B. Self-rated imagery and vividness of task pictures in relation to visual imagery. British Journal of Psychology, 1977, 68, 283-288.

Betts, G. H. The distribution and functions of mental imagery. New York: Teachers College, Columbia University, 1909.

Bower, G. H. Mental imagery and associative learning. In L. W. Gregg (Ed.), Cognition in learning and memory. New York: Wiley, 1972.

Davies, G., & Proctor, J. The recall of concrete and abstract sentences as a function of interpolated task. British Journal of Psychology, 1976, 67, 63-72.

Ernest, C. H. Mental imagery and cognition: A critical review. Journal of Mental Imagery, 1977, 1, 181-216.

Ernest, C. H., & Paivio, A. Imagery ability in paired-associate and incidental learning. Psychonomic Science, 1969, 15, 181-182.

Flanagan, J.C. Flanagan Aptitude Classification Tests. Chicago: Science Research Associates, 1953.

French, J.W., Ekstrom, R.B., & Price, L.A. Manual for Kit of Reference Tests for Cognitive Factors. Princeton, N.J.: Educational Testing Service, 1963.

Gordon, R. An investigation into some of the factors that favour the formation of stereotyped images. British Journal of Psychology, 1949, 39, 156-167.

Gur, R. C., & Hilgard, E. R. Visual imagery and the discrimination of differences between altered pictures simultaneously and successively presented. British Journal of Psychology, 1975, 66, 341-345.

Janssen, W. H. Selective interference in paired-associate and free recall learning: Messing up the image. Acta Psychologica, 1976, 40, 35-48.

Kosslyn, S. M. Information representation in visual images. Cognitive Psychology, 1975, 7, 341-370.

Kosslyn, S. M. Can imagery be distinguished from other forms of internal representation? Evidence from studies of information retrieval time. Memory & Cognition, 1976, 4, 291-297.

Kosslyn, S. M. Measuring the visual angle of the mind's eye. Cognitive Psychology, 1978, 10, 356-389.

Kosslyn, S. M. Image and mind. Cambridge, Mass.: Harvard University Press, 1980.

Kosslyn, S. M., & Pomerantz, J. R. Imagery, propositions, and the form of internal representations. Cognitive Psychology, 1977, 9, 52-76.

Kosslyn, S. M., Ball, T. M., & Reiser, B. J. Visual images preserve metric spatial information: Evidence from studies of image scanning. Journal of Experimental Psychology: Human Perception and Performance, 1978, 4, 47-60.

Kosslyn, S. M., Pinker, S., Smith, G. E., Shwartz, S. P. On the demystification of mental imagery. The Behavioral and Brain Sciences, 1979, 2, 535-581.

Marks, D. F. Visual imagery differences and eye movements in the recall of pictures. Perception and Psychophysics, 1973, 14, 407-412.

McGlynn, F. D., Hofius, D., & Watulak, G. Further evaluation of image latency and reported clarity as functions of image complexity. Perceptual and Motor Skills, 1974, 38, 559-565.

Morelli, G., & Lang, D. Rated imagery and pictures in paired-associate learning. Perceptual and Motor Skills, 1971, 33, 1247-1250.

Morris, P. E., & Gale, A. A correlational study of variables related to imagery. Perceptual and Motor Skills, 1974, 38, 659-665.

Paivio, A. Imagery and verbal processes. New York: Holt, Rinehart, & Winston, 1971.

Paivio, A., Yuille, J. C., & Madigan, S. Concreteness, imagery, and meaningfulness values for 925 nouns. Journal of Experimental Psychology Monograph Supplement, 1968, 76.

Paivio, A., Begg, I. Imagery and associative overlap in short-term memory. Journal of Experimental Psychology, 1971, 89, 40-45.

Richardson, A. Mental imagery. London: Routledge & Kegan Paul, 1969.

Richardson, A. Verbalizer-visualizer: A cognitive style dimension. Journal of Mental Imagery, 1977, 1, 109-126 (a).

Richardson, A. The meaning and measurement of memory imagery. British Journal of Psychology, 1977, 68, 29-43 (b).

Sheehan, P. W. A shortened form of Betts' questionnaire upon

mental imagery. Journal of Clinical Psychology, 1967, 23, 386-389.

Sheehan, P. W., & Neisser, U. Some variables affecting the vividness of imagery in recall. British Journal of Psychology, 1969, 60, 71-80.

Shepard, R. N., & Metzler, J. Mental rotation of three-dimensional objects. Science, 1971, 171, 701-703.

Snyder, C. R. Individual differences in imagery and thought. Unpublished doctoral dissertation, University of Oregon, 1972.

Starker S. Two modes of visual imagery. Perceptual and Motor Skills, 1974, 38, 649-650.

White, K., Sheehan, P. W., & Ashton, R. Imagery assessment: A survey of self-report measures. Journal of Mental Imagery, 1977, 1, 145-170.

Yuille, J. C., & Paivio, A. Abstractness and recall of connected discourse. Journal of Experimental Psychology, 1969, 82, 467-471.

Table 1

Order of Tasks in Individual and Group Sessions

Individual Session Tasks	Group Session Tasks
Picture	VVIQ
Rotate	TVIC
Add/Triangles	VVQ
Add/Stars	Designs
Subtract/Triangles	Figures
Subtract/Stars	Gestalt Completion
Scan	Paper Folding
Integrate	Components
Puzzles	Cube-Cutting
Mazes	Free Recall
Space Relations	Cued Recall

Table 2

Mean Picture Latencies (msec) as a Function of Number of Objects and the Real/Ideal Manipulation

Type of Object	Number of Objects One	Two
Real	2043	2354
Ideal	2200	2668

Table 3

Rotate Proportion Correct as a Function of
Angular Difference and Same/Different Objects

	Angular Difference (degrees)				
	20	60	100	140	180
Same	.96	.89	.82	.80	.85
Different	.84	.77	.80	.77	.78

Table 4

Add and Subtract Mean Latencies (msec) as a Function of Base Form and Ordinal Position of Dot

		Ordinal Position of Dot				
Task	Base Form	1	2	3	4	5
Add	Triangle	2183	2205	2906	3587	3754
	Star	2542	3265	3561	4581	5277
Subtract	Triangle	2513	2559	3545	4202	4413
	Star	2565	2412	3455	4750	4663

Table 5

Correlations and Communalities of Basic Task Measures (x 100)

PIC	RSL	RIN	RNC	ASL	AIN	ANC	SUS	SUI	SUN	SSL	SIN	ISL	IIN	INC	
27	8	-7	-14	2	4	-24	3	9	-26	-11	25	-3	18	-23	PIC
	--	-11	0	38	-32	14	33	-27	2	16	16	-2	2	6	RSL
		--	2	-6	44	-16	4	16	2	24	20	-20	30	-1	RIN
			36	35	-27	41	34	-32	40	1	17	10	-9	40	ANC
				92	-34	39	90	-34	52	-22	10	7	16	15	ASL
					73	-24	-22	66	-20	1	-6	-7	15	-10	AIN
						65	37	-39	78	-4	-5	-2	11	34	ANC
							92	-48	50	-19	0	14	9	23	SUS
								81	-34	10	1	-12	22	-32	SUI
									70	-5	-5	8	10	40	SUN
										16	11	1	-7	8	SSL
											22	-2	2	-8	SIN
												71	-76	21	ISL
													73	-10	IIN
														36	INC

PIC - Picture Mean Time
RSL - Rotate Slope
RIN - Rotate Intercept
RNC - Rotate Number Correct
ASL - Add Slope
AIN - Add Intercept
ANC - Add Number Correct
SUS - Subtract Slope
SUI - Subtract Intercept
SUN - Subtract Number Correct
SSL - Scan Slope
SIN - Scan Intercept
ISL - Integrate Slope
IIN - Integrate Intercept
INC - Integrate Number Correct

Table 6

Correlations for Basic Tasks Including Composite Measures (x100)
Number of Subjects Varies from 50 to 79

PIC	RSL	RIN	RNC	SLP	INT	ACC	SSL	SIN	IRT	INC	
	8	-7	-15	18	7	-27	-11	25	21	-24	PIC
		-12	1	37	-34	9	17	14	-2	5	RSL
			-1	2	35	-8	21	21	28	0	RIN
				17	-32	43	2	16	-4	39	RNC
					-25	0	-21	9	23	0	SLP
						-34	6	-3	21	-23	INT
							-5	-6	19	39	ACC
								10	-12	8	SSL
									5	-7	SIN

PIC - Picture Mean Time
RSL - Rotate Slope
RIN - Rotate Intercept
RNC - Rotate Number Correct
SLP - Add & Subtract Slope Corrected for Accuracy
INT - Intercept for Add and Subtract Tasks
ACC - Number Correct for Add and Subtract Tasks
SSL - Scan Slope
SIN - Scan Intercept
IRT - Integrate Mean Time
INC - Integrate Number Correct

Table 7

Summary Statistics for Standard Spatial Ability Tests

Test	Correct Responses Mean	Std.Dev.	R	Incorrect Responses Mean	Std.Dev.	R
Designs	21.53	6.73	.924	.143	.663	.879
Figures	20.66	5.66	.878	1.53	2.90	.790
Paper Folding	10.18	4.23	.897	3.32	3.31	.420
Components	10.58	4.82	.894	1.93	2.01	.400
Space Relations	41.29	12.7	.945	5.72	5.91	.885
Cube-Cutting	2.48	1.42	.736			

Table 8

Correlations and Communalities of Spatial Ability Tests (x 100)

CMPNT	PRFLD	FGURS	DSGNS	SPCRL	CUBCT	PUZLS	MAZES	
62	60	40	52	62	65	-47	-48	CMPNT
	43	40	39	60	40	-37	-41	PRFLD
		40	42	54	42	-50	-46	FGURS
			47	57	40	-35	-43	DSGNS
				73	55	-55	-58	SPCRL
					47	-41	-43	CUBCT
						39	36	PUZLS
							41	MAZES

CMPNT - Components
PRFLD - Paperfolding
FGURS - Figures
DSGNS - Designs
SPCRL - Space Relations
CUBCT - Cube-Cutting
PUZLS - Puzzles
MAZES - Mazes

Table 9

Basic Task Measures with Significant Beta Weights from Regression Analyses of Spatial Ability Measures

Spatial Task	Excluding Rotate Basic Task Measures	r	Including Rotate Basic Task Measures	r
CMPNT	RNC PIC	.47	RNC	.42
PRFLD	RNC IRT SEX ACC	.63	RNC IRT	.54
FGURS	ACC IRT RNC	.55	ACC RSL IRT INT	.68
DSGNS	RNC	.45	RNC RIN	.58
SPCRL	RNC IRT ACC	.55	RNC RSL IRT ACC RIN	.70
CUBCT	PIC RNC IRT	.46	PIC RIN	.44
PUZLS	RNC INT	.48	RNC RIN SEX	.63
MAZES	ACC IRT	.48	ACC IRT	.48

PIC - Picture Mean Time
RSL - Rotate Slope
RIN - Rotate Intercept
RNC - Rotate Number Correct
SLP - Add & Subtract Slope Corrected for Accuracy
INT - Intercept for Add and Subtract Tasks
ACC - Number Correct for Add and Subtract Tasks
SSL - Scan Slope
SIN - Scan Intercept
IRT - Integrate Mean Time
INC - Integrate Number Correct
SEX - Sex of the Subject

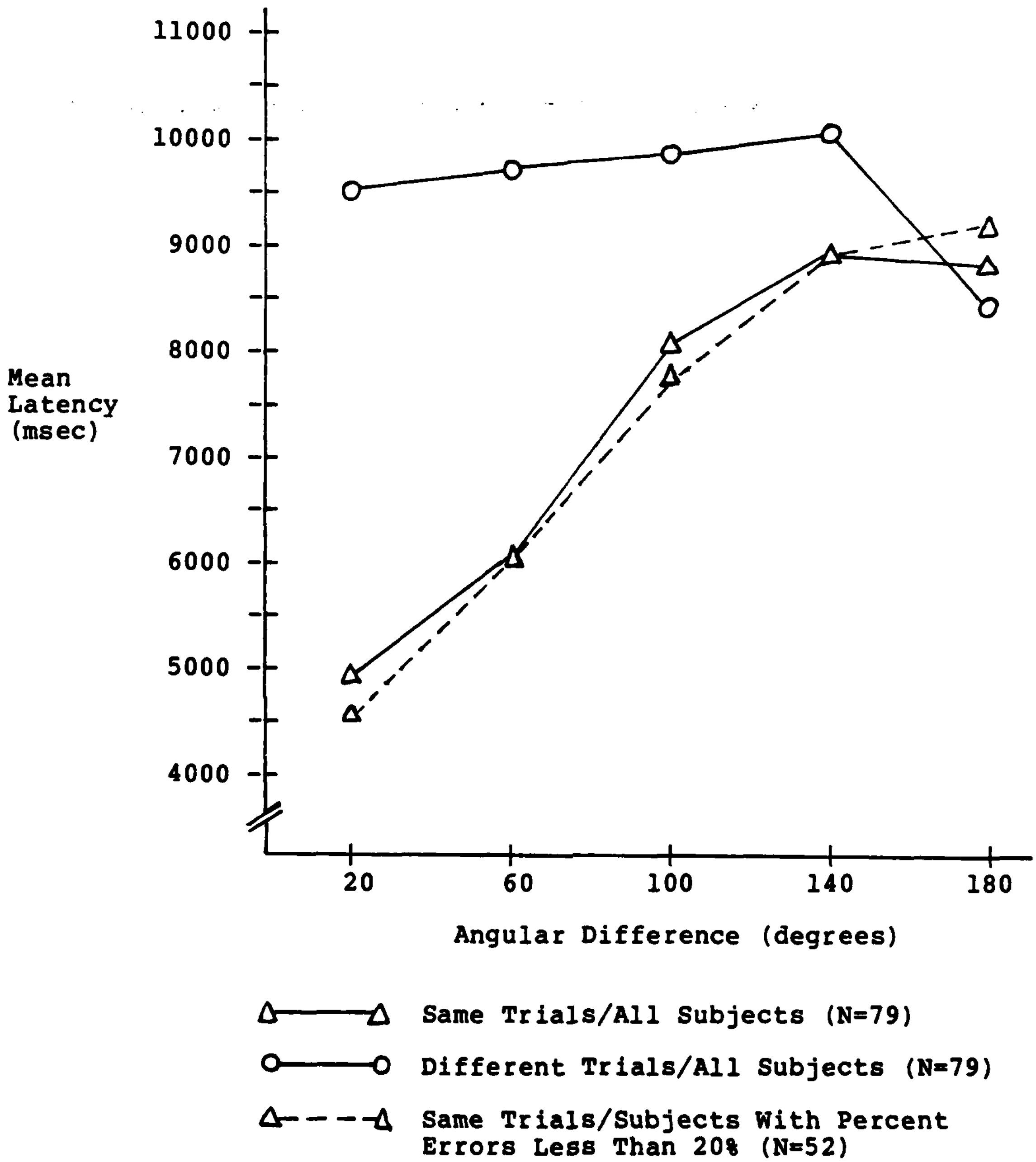
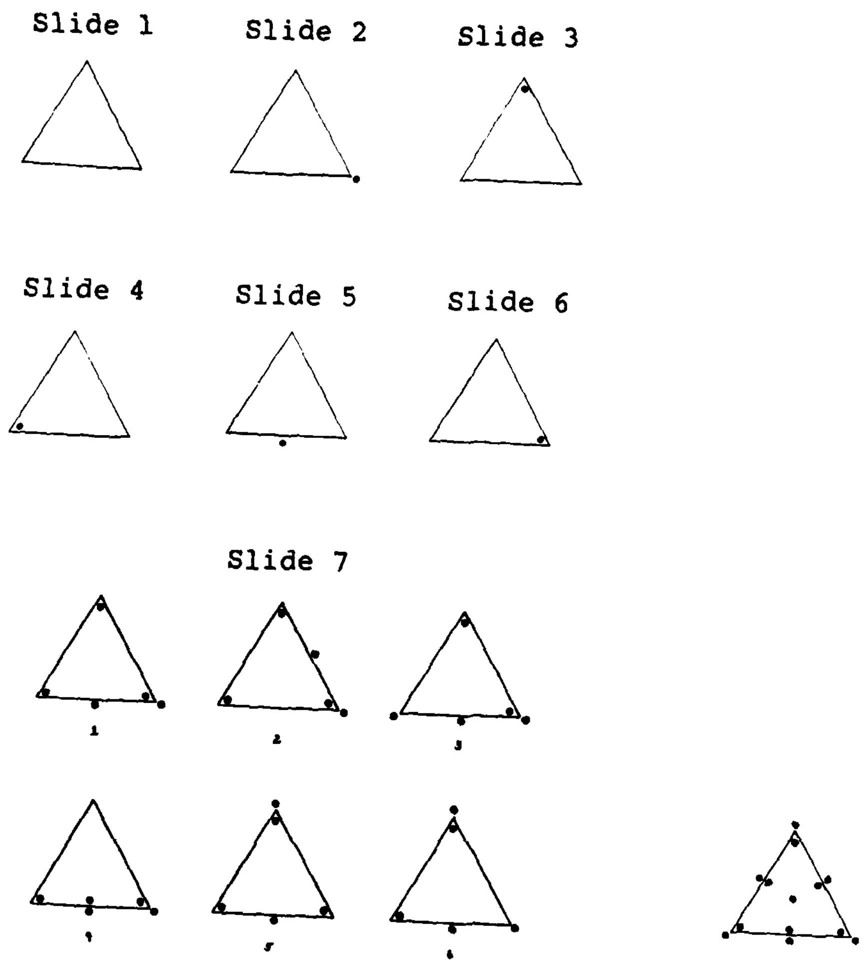


Figure 1. Rotate Mean Latencies for Correct Responses as a Function of Angular Difference and Same/Different.



(a) (b)

Figure 2. Add/Triangle Task: (a) Sample Problem; (b) Thirteen Dot Positions Used in Task.

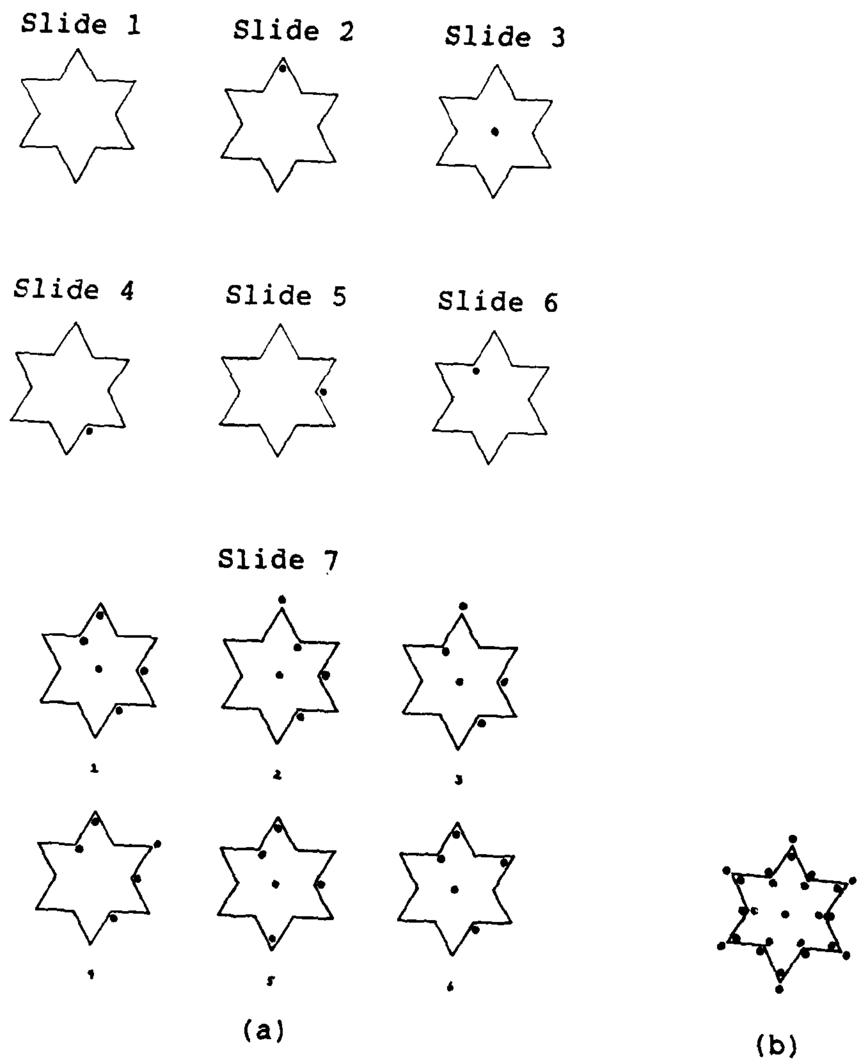


Figure 3. Add/Star Task: (a) Sample Problem; (b) Twenty-Five Dot Positions Used in Task.

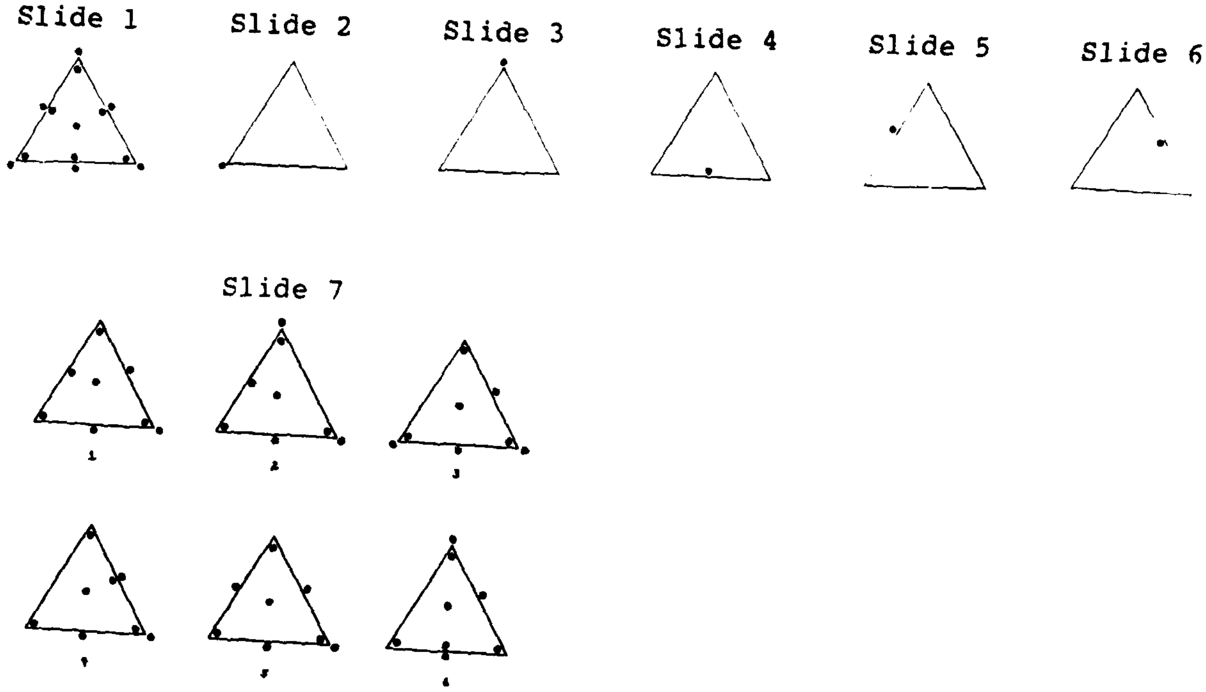


Figure 4. Sample Subtract/Triangle Problem.

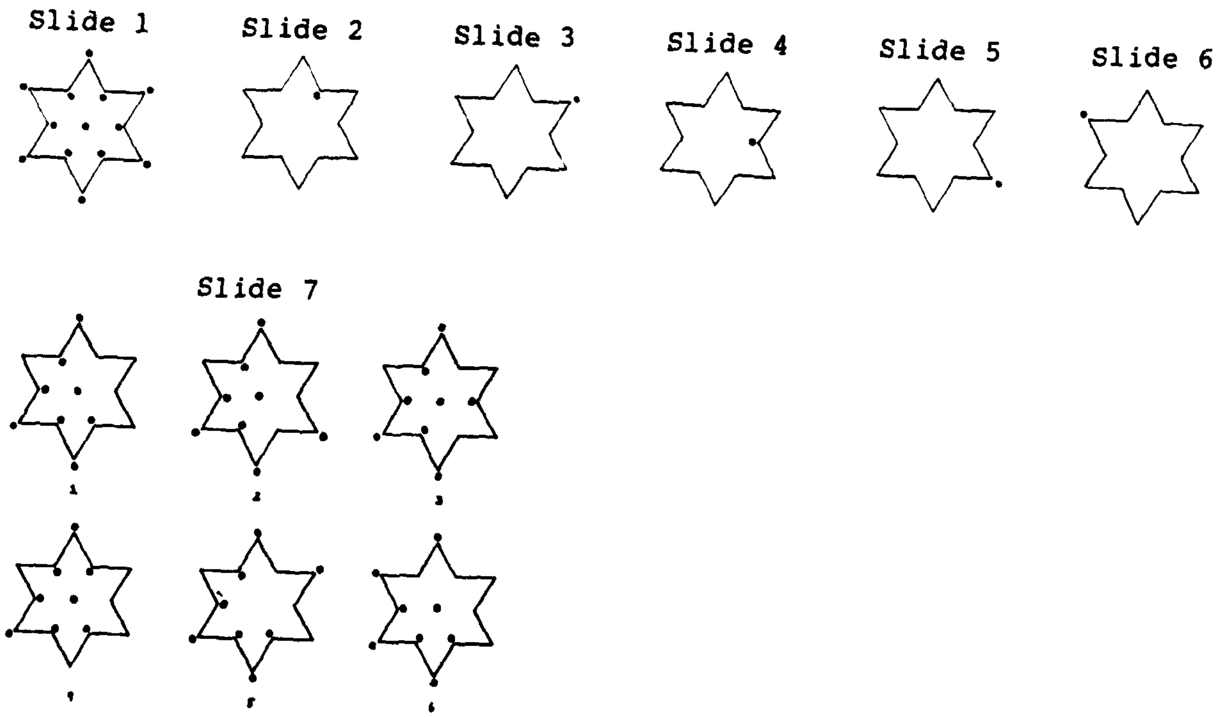


Figure 5. Sample Subtract/Star Problem.

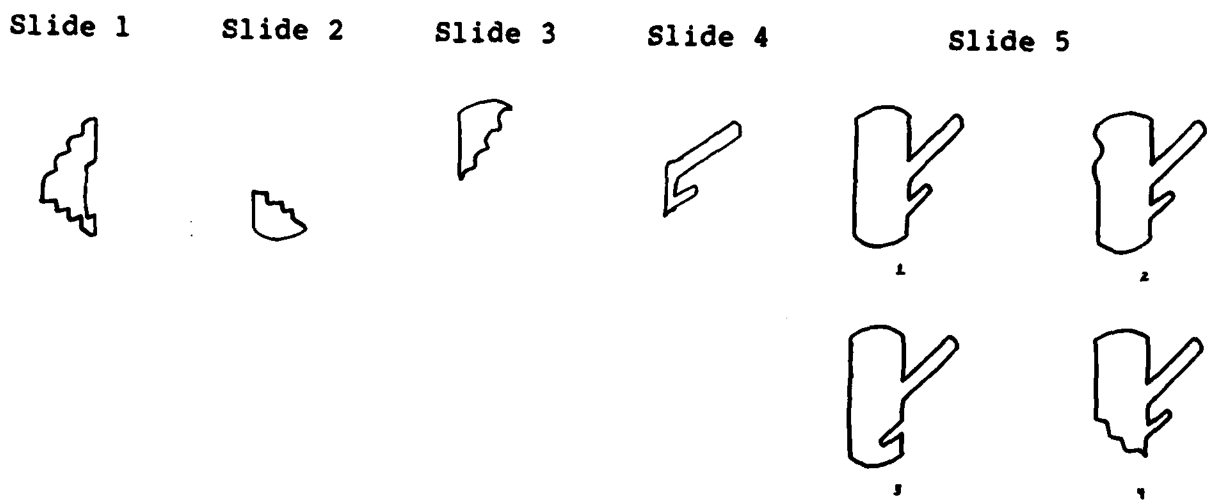


Figure 6. Sample Integrate Problem.

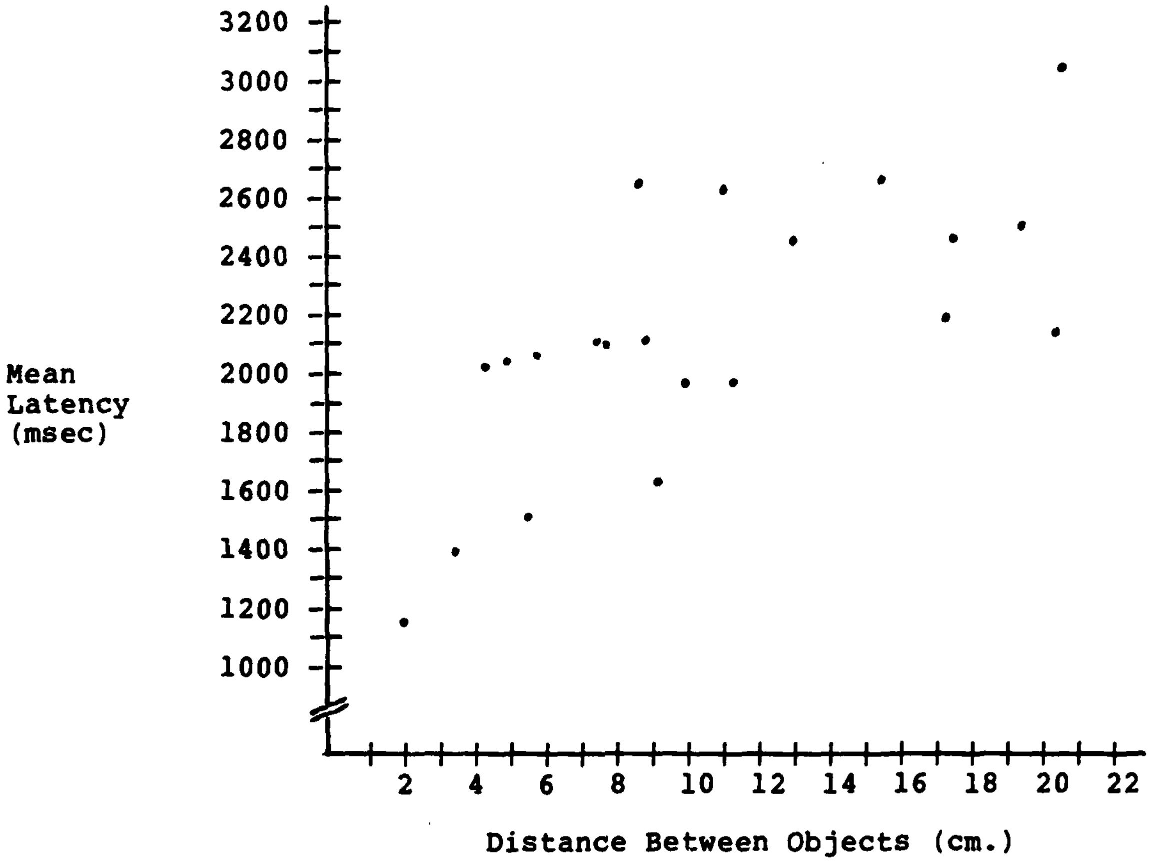


Figure 7. Scan Mean Latencies as a Function of Distance Between Objects on the Map.

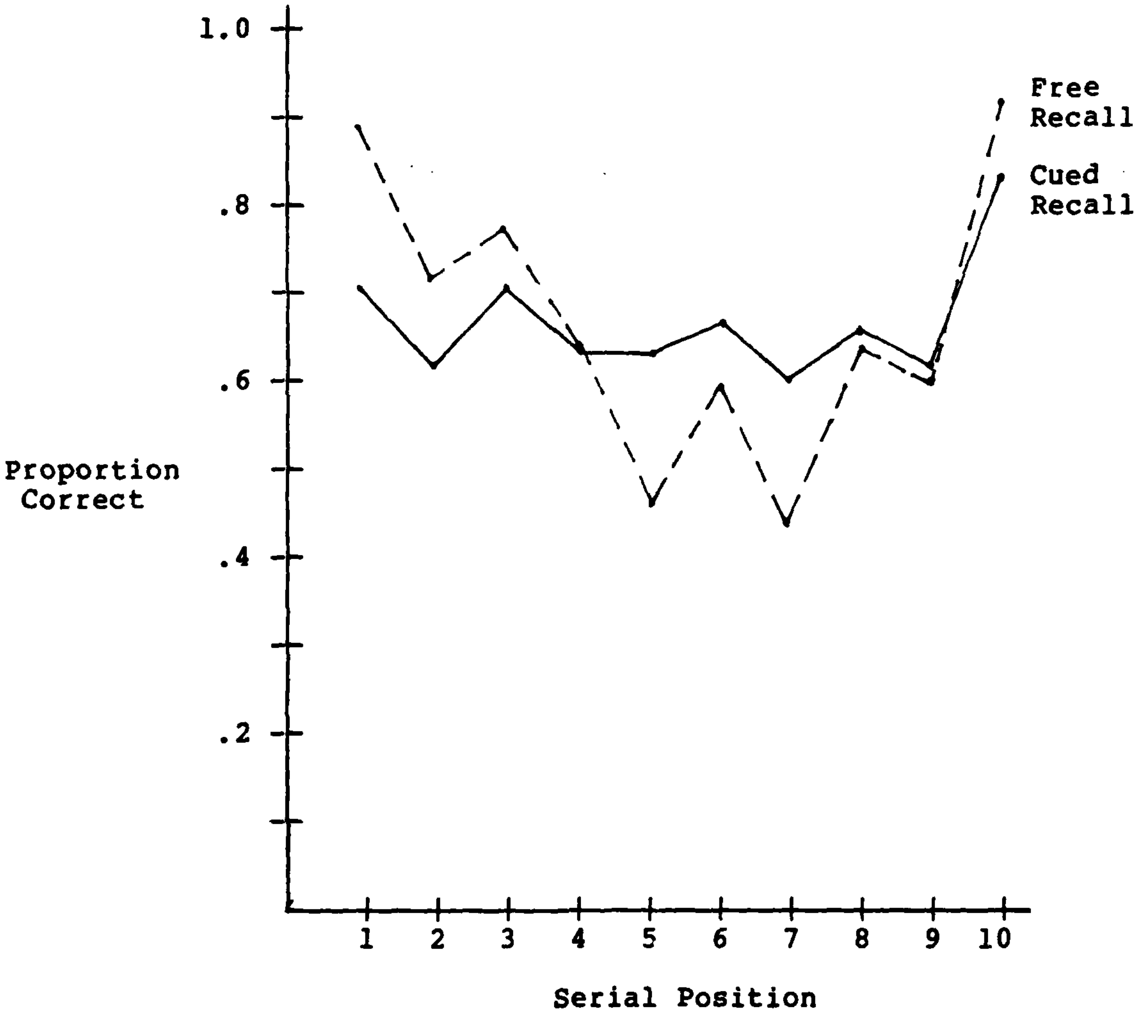


Figure 8. Proportion Correct as a Function of Serial Position for Free and Cued Recall. Pairs of Adjacent Serial Positions Were Pooled Together for Cued Recall.

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